ELECTRIC AND DIESEL-ELECTRIC LOCOMOTIVES

FRONTISPIECE

Great Northern Railway (U.S.A.) fast fruit special hauled by 5400 h.p. diesel-electric locomotive.

ELECTRIC AND DIESEL-ELECTRIC LOCOMOTIVES

BY

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PREFACE

WHILST many railway engineers and connoisseurs are familiar with all the modern types of steam locomotive from the diminutive shunter to the latest American divided-drive and articulated passenger and freight locomotives, only a small proportion have more than a general outline of knowledge of the two new types, namely, the electric locomotive and the diesel-electric locomotive. Of these the former has been in use for some forty years in various countries, but only in the last twenty years has its development become so apparent. The diesel-electric locomotive has come into its own in the last ten years and in the United States of America is sweeping all other types of locomotive before it.

With the idea of setting out the essential requirements of such locomotives, the authors have drawn up chapters dealing with motors, control gear, auxiliaries, diesel-engines, generators and the constructional features of the locomotives themselves. To complete the picture, appendix tables have been compiled which give as much general information as possible to enable all interested to study the development of these new methods of railway motive power. Locomotive engineers and designers will recognise the value of these tables for reference purposes and for this reason considerable care has been taken to ensure that these are as accurate as possible.

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In conclusion, the authors would be very pleased to be notified of any inaccuracies which engineers may discover in the tables and of any further entries considered suitable for later editions.

CONTENTS

CHAPTER ONE

THE MODERN LOCOMOTIVE

THE character of motive power in railway operation is always directly related to the problems of operation; and choice of the type of locomotive to be used by any particular railway organisation depends mainly on traffic conditions, geographical situation and the source of energy. In recent years two new types of locomotive have come into general use in addition to the steam locomotive; these are the electric locomotive and the diesel-electric locomotive.

Electric Locomotives. At the present day the electric locomotive almost reigns supreme in countries such as Sweden and Switzerland, whilst very extensive additional electrification is to be carried out in France and Austria. In all these countries considerable quantities of hydro-electric power are available, making such general schemes an economical proposition on account of the fuel saving. In addition to these, many other countries have some electrification system either of the intensive traffic type or over difficult country.

Where a very large amount of traffic has to be dealt with, considerable improvements in operating conditions can be effected by the use of electric locomotives, the one outstanding example of such an intensive system being that of the Pennsylvania Railroad between New York, Philadelphia and Washington in the U.S.A. Here, over a route of 225 miles, both passenger and freight traffic is handled by electric locomotives and is of such density as to make the line famous for its daily train-mileage and high speeds of operation.

In mountainous or difficult country, electric haulage is frequently resorted to as a means of increasing the maximum traffic density and the average overall speed of the trains, besides making for economy in power consumption and brake shoe wear by the employment of electric braking on the regenerative system. For such work locomotives are frequently of a smaller type with a rating of 1200 to 1500 horse-power and are equipped for multiple-unit operation in which up to four such locomotives may be

coupled together and controlled by a single driver in the cab of the leading unit. An excellent example of such a system is that of the Pietermaritzburg-Durban section of the South African Railways in Natal which is operated by 180 locomotives of 1200 horse-power each. Gradients over this line are very severe, and the employment of electric haulage has considerably improved operating conditions and overall timing of both passenger and freight traffic.

In Great Britain the electrification of the former London and North Eastern Railway between Manchester, Sheffield and Wath comes into this difficult country category and the company intend, by the employment of this type of motive power, to improve traffic conditions through the three miles long Woodhead tunnel and, in addition, to reduce considerably assisting engine mileage. The locomotives to be used on this line are described and illustrated in Chapter Five. Other electric locomotives employed, or formerly employed, in this country have been very limited in scope, the chief examples being the following.

The passenger locomotives of the former Metropolitan and allied railways built for hauling through trains from the outer-suburban steam-operated sections over the underground lines.

The goods locomotives of the North Eastern Railway's Newport-Shildon mineral line in Durham county. These locomotives, ten in number, are still in existence, though out of traffic, and were originally built to the design of Sir Vincent Raven in 1914.

An experimental 4-6-4 express passenger locomotive was also constructed in 1923 by the North Eastern Railway and subjected to extensive tests over the Shildon line. This locomotive was capable of hauling heavy trains at speeds up to 90 miles per hour and, as it is still in existence, the authors have frequently heard the hope expressed that it be utilised on the Manchester–Sheffield section when completed. It is illustrated in Fig. 1.

Considerable interest is attached to the two new Southern Region electric locomotives which can handle both express passenger and heavy mineral trains without difficulty. Details of the locomotives, which are still in their experimental stages, are somewhat sparse and, in consequence, a full description is not available. It is known, however, that motor-booster sets are employed for speed regulation and that a tractive effort can be maintained for a short period after the power supply ceases, a very useful advantage

where the locomotive collects its power from a third rail with resultant supply interruptions at points, junctions, level crossings and similar places.

Throughout the world the types of electric locomotive employed and the character of their power supply differ considerably. For the latter, direct or alternating current may be utilised and the various railway organisations differ in their opinions as to which system is the better. The following table gives some details of operating voltages and types of supply. It should be noted that

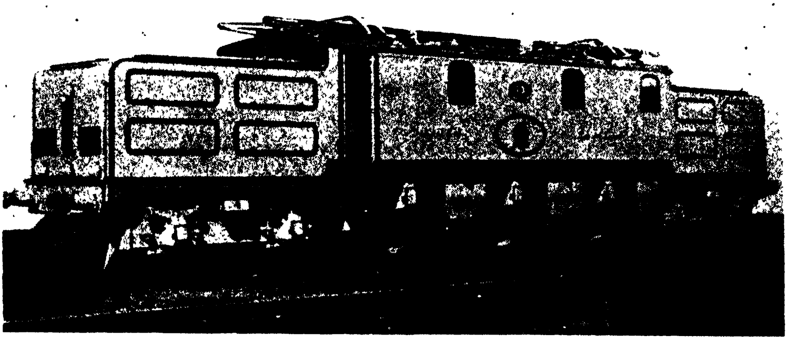


FIG. 1. The first British electric express locomotive.

the general system is given in each case and this does not imply that no other is in use.

Great Britain	Direct Current	600 and 1500 volts
France	Direct Current	1500 volts
Germany	Alternating Current (1 phase)	15000 volts $16\frac{2}{3}$ cycles/sec.
Poland	Direct Current	3000 volts
Sweden Norway Switzerland	Alternating Current (1 phase)	15000 volts $16\frac{2}{3}$ cycles/sec.
Hungary	Alternating Current (1 phase)	16000 volts 50 cycles/sec.
Italy	Alternating Current (3 phase)	3000–3700 volts
	Direct Current	3000 volts
South Africa	Direct Current	1500 and 3000 volts
India	Direct Current	1500 volts

U.S.A.	Alternating Current (1 phase)	11000 volts 25 cycles/sec.
	Direct Current	650 volts

In general, the types of electric locomotive can be split into three classes according to the power supply at the trolley wire or conductor rail and to the traction motors. These classes comprise the following :

(a) The direct current locomotive operating on voltages up to 3000 and with traction motors operating direct or in combination from this supply.

(*b*) The alternating current locomotive, using a high-tension supply and feeding its traction motors with low-tension power obtained by means of a transformer carried on the locomotive.

(*c*) Locomotives of the convertor type in which the supply to the motors is of a different character from that obtained from the overhead line.

These three classifications are dealt with separately in three consecutive chapters, and readers will appreciate the entirely different characteristics of each type.

The three-phase locomotive is employed at the present day on the Italian State Railways only and is considered obsolete. Conversion to 3000 volt direct current operation is to be carried out as and when opportunity occurs, in order to bring such sections to conform with the more recently electrified sections. In consequence, this type of equipment is dealt with briefly and only as a matter of interest, it should not be considered as up-to-date practice.

Diesel-Electric Locomotives. The diesel-electric locomotive has come to the fore during the last ten years, especially in the United States of America where new construction during recent years has shown an ever-increasing proportion of the diesel-electric. For example, the most recent statistics show that of 856 locomotives on order in the U.S.A., 148 are steam, 702 diesel-electric and 6 electric.

For express passenger purposes this type of locomotive is ideal, as, amongst other advantages, it is capable of travelling 2000 to 3000 miles without being detached from its train, refuelling being an operation of only a few minutes duration. Absence of grit, smoke and a considerable reduction in noise makes for passenger comfort, whilst the operating crew are comfortably

housed with the driver near to the leading end of the locomotive where he has a wide field of vision and the engines, etc., readily accessible for inspection while the locomotive is in motion. Reliability is also a leading factor, one particular example recently recorded being on the running of three 4000 h.p. locomotives of the Chicago Burlington and Quincy Railroad which averaged 1,249,500 miles before a major overhaul became necessary. Besides the possession of such staying power, the external appearance of these locomotives, which is frequently arranged to conform with their trains, is pleasing to the eye and this, combined with the comfort and high-speed transportation provided, has resulted in an increase in passenger traffic and revenue on the railways operating them. With a few exceptions, relics from the 1935–8 period, all passenger locomotives are built up from 2000 h.p. units, these being used singly or in combinations of two or three to give 4000 and 6000 h.p. respectively. The driving cab is fitted at the leading end of the first unit, incorporated in a streamlined nose, the other units being controlled from this position and having no separate driving cabs. Some 300 of these 2000 h.p. units were in operation on Dec. 31, 1946, and more than 100 further units were on order from the leading manufacturers.

For long-distance freight traffic the Electromotive division (General Motors Corporation) built an experimental four-unit locomotive of 5400 h.p. in 1939. This made demonstration runs on several of the major U.S. railroads and proved so popular that large numbers were immediately ordered. Certain railways have completely converted the freight motive power on certain divisions to diesel haulage, and the resulting improved schedules with trains of 4000 to 5000 tons helped considerably where the vast increase in war traffic to the Pacific coast had to be handled over very lengthy mountainous single-line sections. One, two and three unit locomotives rated at 1350, 2700, 4050 h.p. have been built in small quantities, but the majority of purchasers preferred the four-unit machine, more than 300 of which are at present in traffic. Improvements in engine and motor design have recently increased the rating of these locomotives to 6000 h.p., i.e. 1500 h.p. per unit.

In the shunting and short-distance freight traffic field the American diesel-electric locomotive holds an almost complete monopoly of new construction due to the ideal characteristics of this form of motive power for such duties. The chief advantages are ;

(*a*) Full engine horsepower available for traction giving a high starting and low speed tractive effort.

(*b*) Maximum power always available on demand, with almost negligible power consumption when standing by.

(*c*) Excellent visibility and comfortable operating conditions can be provided for the driver, making the locomotives popular with their crews.

(*d*) Visits to locomotive depot for refuelling, fire-cleaning, etc., are eliminated, as sufficient fuel can be carried for several days' operation.

(*e*) Reliability and availability are very high.

The only diesel-electric locomotives operating in this country are of the shunting type of which some ninety have been built with others on order. A passenger locomotive was operated experimentally on the London and North Eastern Railway in 1933, but was never placed in regular traffic. Experiments however are now being carried out with main-line diesel-electric locomotives by British Railways (London Midland Region).

Passenger diesels have been built in this country for service in South America and other countries and considerable interest is anticipated in the new Egyptian State Railways locomotives, twelve in number, being built here.

On the Continent a number of shunting locomotives are in service in France including several American-built machines and some low-powered passenger locomotives in Denmark and Switzerland. Other countries have operated small units experimentally but not adopted them for general utilisation. Three main-line locomotives of 4000 h.p. have been built, two for the French railways and one for Roumania, but, although these are quite successful, no immediate increase in numbers is anticipated.

From this brief review readers will appreciate that the diesel-electric locomotive is in the main confined at present to the western hemisphere, but considerable expansion in Europe is anticipated now that the post-war phase has arrived.

So much for the general aspect of utilisation of electric and diesel-electric locomotives. Turning now to the component parts and equipment of such locomotives, the first item to be dealt with is the electric traction motor, the portion of the equipment which is common to both and actually provides the torque and tractive power of the locomotive.

CHAPTER TWO

TRACTION MOTORS FOR LOCOMOTIVES

TRACTION motors for locomotives can be divided into two completely-differing types; the series commutator motor as used for direct current and with modifications for single-phase alternating current locomotives; and the three-phase A.C. induction motor as employed on three-phase systems and on phase-convertor locomotives.

The Direct Current Traction Motor

The type of motor most suitable for traction purposes is the series machine, as the working range of magnetic flux is well below the saturation value (i.e. the maximum obtainable), and, in consequence, the torque exerted by the armature is proportional to the square of the current throughout the speed range, resulting in a very high starting torque and a low torque at high speed. Should increased torque be required at the upper end of the speed range, this may be obtained by reduction of the main field flux, which causes an increase in armature current and torque for any given speed. Reduction of the flux may be obtained by two methods, these being:

(*a*) The provision of tappings on the field coils so that sections of the winding may be cut out of circuit.

(*b*) Connection of a diverting resistance in parallel with the field coils. When the increased torque is required, this resistance is brought into circuit and by-passes a portion of the field current. Fig. 2 shows the relevant connections in the motor circuit and a typical characteristic.

As a result of these characteristics the series motor, incorporating tappings or diverting arrangements where necessary for obtaining improved speed-torque characteristics, is universally employed on electric locomotives and has now many years of satisfactory service to its credit. In comparison with the commercial type of machine considerable differences in construction are necessary, as the traction motor must be capable of withstanding severe vibration, mechanical shock and heavy sustained overloads.

Further, protection must be devised against dust and grit picked up from the track and passed into the motor interior with the ventilating air.

Having briefly discussed the reasons underlying the use of the series motor as that most suitable for traction purposes, an outline

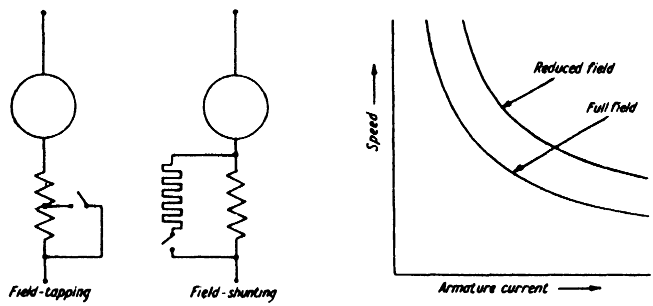


FIG. 2. Connections for field-weakening of series motor with typical characteristic.

of the constructional details of typical machines will serve to illustrate the main points of modern design.

Constructional Details

The Magnet Frame. The main motor frame is constructed of steel either cast in a box pattern or fabricated from rolled steel plates. At each end this frame has an opening bored and recessed to accommodate the two end-plates carrying the armature bearing housings, these being secured to the frame by suitable steel screws. Access to the commutator and brushgear is provided by suitable openings cast or cut in the frame and fitted with dustproof detachable sheet-metal covers.

As outlined later in this chapter, the method of motor suspension depends on the type of transmission to be employed between armature shaft and road-axle. Where the motor requires an axle-way for road-axle or quill-shaft support, this is cast or fabricated into the body of the frame and fitted with suitable bearings with detachable axle-caps, Fig. 3.

Field Poles. Field pole-pieces, whether for main or auxiliary purposes, are built up from thin laminated steel stampings, each coated with a thin film of insulating material, the whole being clamped and riveted together between steel end-plates. The insulation between laminations serves to minimise any losses due

to induced circulating or "eddy" currents. The assembled pole-pieces are bolted to machined seatings on the interior of the frame and each carries a field coil clamped in position by spring-washers and protected by insulated packing pieces.

Field Coils. Main shunt field coils are built up of several layers, each consisting of a large number of turns of insulated copper wire. Series and auxiliary field coils are wound with flat copper strip, insulated between turns and layers with mica. In

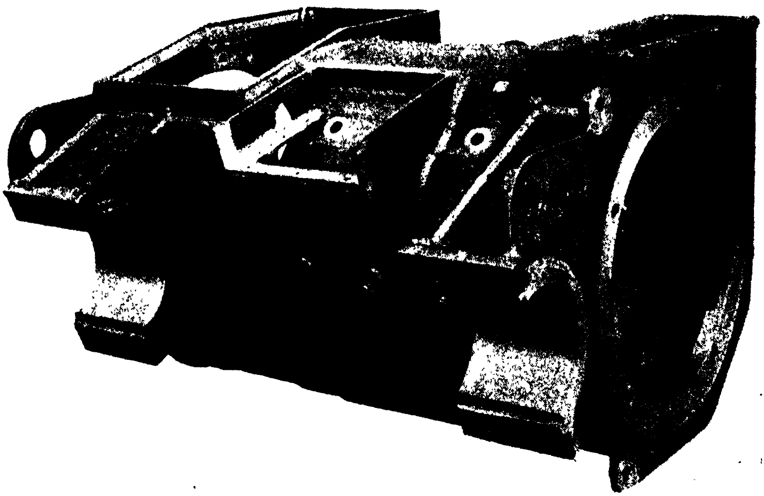


FIG. 3. Machined cast-steel frame for nose-suspended motor.

order to obtain the necessary tension and symmetry in shape and size, machine winding is employed, the coil being wound on a frame or "jig" which is removed when the operation is completed. After winding, the coil is then bakelised and pressed to shape; next, it is wrapped with mica or glass fabric and covered with webbing or glass fabric as an outer protection; then, finally, the coil is dipped into insulating varnish and baked to produce a hard moisture-proof surface. Terminals are either riveted or brazed to the end of the coil except with certain shunt windings where a short piece of suitable wire is joined to the end of the winding.

The use of auxiliary field coils or "interpoles" has not been previously mentioned. Similar in construction to a series field

coil but reduced in size, these windings are placed in the space between two adjacent main field poles and serve to effect considerable improvement in commutation, i.e. they minimise sparking

Fig. 4. Field coil and pole components.

between brushes and commutator. Figs. 4 and 5 show the various components of a field winding and pole-piece, together with a

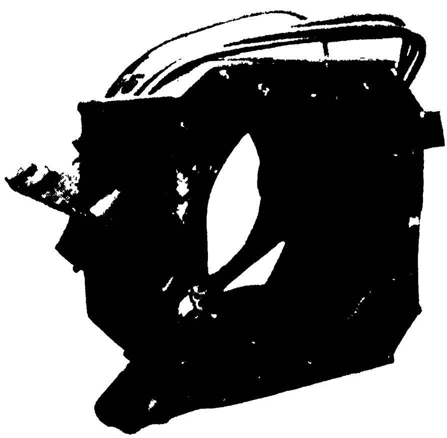


Fig. 5. Motor frame with series and auxiliary field windings in place.

frame in which both the main and interpole windings have been completed.

Armature Core and Shaft. The armature core is built up from a number of thin circular steel stampings, or laminations, each coated with a film of insulation in the same manner as described for pole-pieces. Ducts are provided through these stampings to allow the passage of air for cooling purposes, and slots run transversally across the surface of the complete assembly in order to accommodate the armature coils. The whole is supported by a steel spider mounted on the armature shaft, with keys and other locking devices to ensure rigidity. The commutator is usually mounted on an extension of the spider to enable the shaft to be extracted if necessary for maintenance purposes, without disturbing any portion of the assembly or windings.

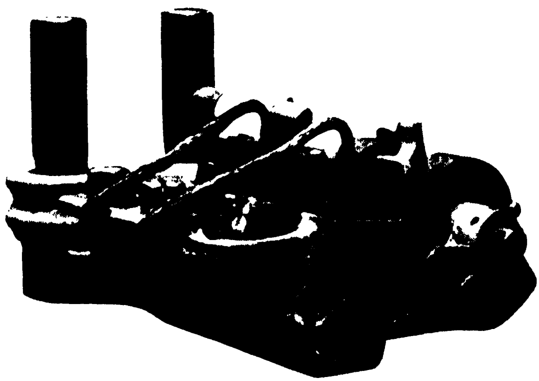


FIG. 6. Typical brush box assembly.

Commutator. The commutator is built up from a number of specially shaped hard-drawn copper segments, clamped together in a cylindrical form by special end-flanges and mounted on a steel hub keyed to the main spider. Each segment is insulated from its neighbours by pure mica and has " vee " notches machined in each end for clamping purposes. Steel " vee " or clamping rings are employed to clamp the whole assembly together in order to prevent distortion due to centrifugal or other stresses, and carry circular micanite mouldings on the clamping faces to insulate them from the segments.

Brushgear. In order to feed the current to the armature, some form of brushgear is necessary. A traction motor may possess two, four, six or more sets of brush-holders, each with one or more brushes, depending on the armature winding and the number of

main poles. Each brush-holder is mounted on the motor frame and it supports the brushes so as to allow them to move in a radial direction only. Provision is usually made in the mounting to permit adjustment of the holder to allow for commutator wear. The brushes fit into rectangular slots and are maintained in tension against the commutator by springs, these being shunted by copper " pigtails " to protect them from damage due to excessive current. The brushes are made of graphite and, according to the design and service requirements, may vary widely in hardness and other characteristics.

Armature Windings. Two types of winding are in use for modern direct current traction motors—the wave winding and the lap winding. These two systems differ in the method of interconnection and the relative positioning of the armature conductors themselves and their appropriate commutator segments with the result that there are always two paths only through a wave winding, but as many paths as main poles on the frame with a lap winding.

Until recent years all traction motors except those for large output had wave-wound armatures, due to the inherent property of such a two-circuit winding that the electrical circuits are always balanced even when unequal magnetic fluxes occur in the frame and that in consequence no equalising circuits are required. Further, where space limitations permit, only two sets of brush-holders are necessary. In present day practice, however, quite a large number of locomotive traction motors have lap-wound armatures with equalising connections both for ease in construction and design flexibility.

As mentioned earlier, the coils or winding elements fit into slots running transversally in the surface of the core and several conductors are normally incorporated into each element. The wave-winding coils are open-armed and the lap type closed. To prepare a coil element, the required number of copper-strips of the necessary cross-section to carry the rated current are each formed to the requisite shape. Each conductor is then annealed and insulated throughout its length with mica tape. The group of conductors is then assembled together, bakelised, wrapped with further mica tape over the slot portions and given an outer wrapping of asbestos tape. The composite coil so formed is then bakelised again and hot-pressed on the slot portion to obtain the dimensions necessary to fit exactly into the core slot. Recent

developments in this direction are the use of asbestos cloth and paper, glass fabrics and tapes, and synthetic high-temperature varnishes. These permit thinner insulation and hence for a given slot size allow an increase in the copper section which, coupled with the improved heat transfer due to the thinner insulation, results in an increase in the rating of the armature.

The operation of winding the armature comprises the fitting of the coil elements into the core slots and the installation and soldering of the coil conductor leads into their respective commutator riser lugs. Each slot is of sufficient depth to accommodate two coil elements and the winding consists of two layers, each element having one limb in the lower layer and one in the upper, the relative positions of the two limbs of any particular coil being governed by the pitch of the winding. The overhanging ends of the coils are supported by and insulated from the armature spider and protected externally by layers of mica, glass fabric or other suitable webbing. When all the coils have been fitted into position, the slots are sealed over with insulated packing strips and special high-tensile steel bands are placed at several points along the periphery to hold the whole assembly against distortion by centrifugal and other forces. Each band is made up of several turns of wire applied at a specified tension, soldered and held together in special clips. Finally, the armature is treated with insulating varnish and baked thoroughly to obtain a hard moisture-resistant surface.

Bearings and Lubrication. Locomotive traction motors employ sleeve axle-bearings when axle-mounted or for quill shaft support, but their armature bearings may be of either the sleeve or the anti-friction type.

Sleeve bearings for armature shafts are built up of either brass or bronze bushes lined internally with white metal and lubricated by means of grooves cut in the bearing face. Oil is contained in a reservoir built into the housing adjacent to the bearing, rectangular apertures being cut in the bushes through which the oil is syphoned, by means of wool or cotton waste, on to the shaft. For road axles, the babbit lining is frequently omitted or is replaced by a thin coating of tin, a practice popular in the U.S.A. for high-speed applications. The bush is cut in two halves to facilitate removal and, when in position, is held there by a detachable "axle-cap," which contains the oil reservoir and syphoning arrangements.

When employed for armature support, the sleeve bearing introduces a disadvantage into the motor design in that the gap between the pole-tips and the armature must be sufficient to allow for displacement of the latter due to wear in the bearings. This necessitates the use of a more powerful field winding in order to obtain a given flux. In addition, once some wear has taken place, the pole-fluxes become unbalanced, and, although this point causes no difficulty when the armature is wave-wound, if a lap winding be used, then heavy circulating currents will be set up in the equaliser rings. As a result of this difficulty most modern machines are fitted with bearings of the anti-friction type.

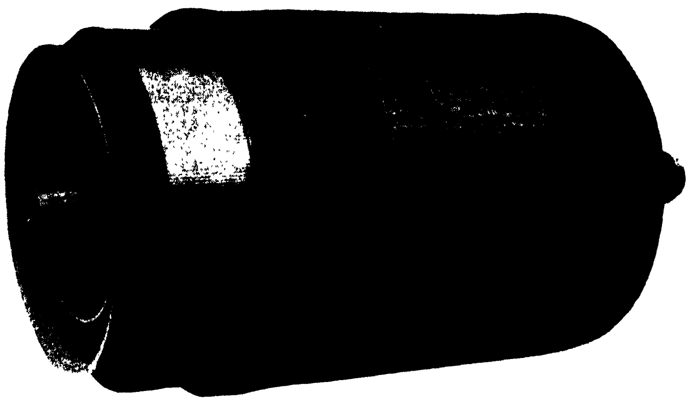


FIG. 7. Completed railway motor armature.

Two types of anti-friction bearing are available—the ball bearing and the roller bearing. Although the former is used to a small extent, the roller bearing is the more suitable and its application is very extensive. Other advantages obtained by its use include considerably higher journal load capacity, improved efficiency and ease of maintenance.

Motor Ventilation. Three methods of ventilation are in use for traction motors. In brief, they are the following :

(*a*) The totally enclosed machine in which the interior is sealed off from the atmosphere and cooling is restricted to air-circulation over the frame surface, this being ribbed on occasion to increase the cooling area. Air circulation may be natural or assisted as in the " Emcol " type motor where a fan is employed to circulate the air through tubing fitted into the frame exterior.

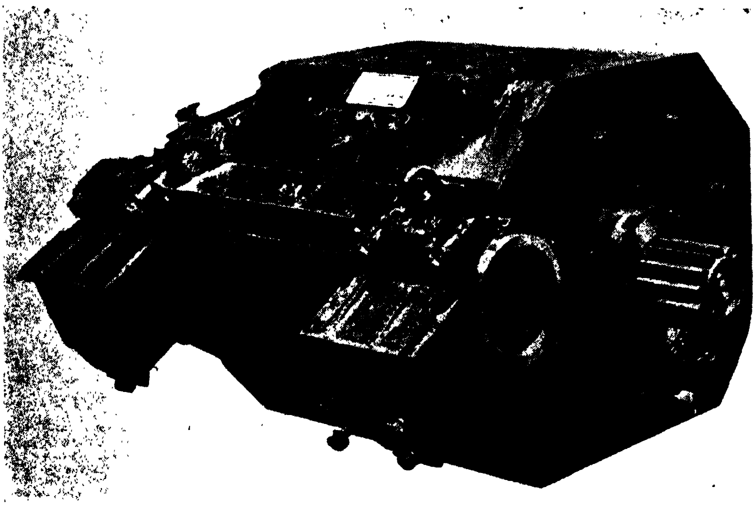


FIG. 8A. "Emcol" totally-enclosed traction motor.

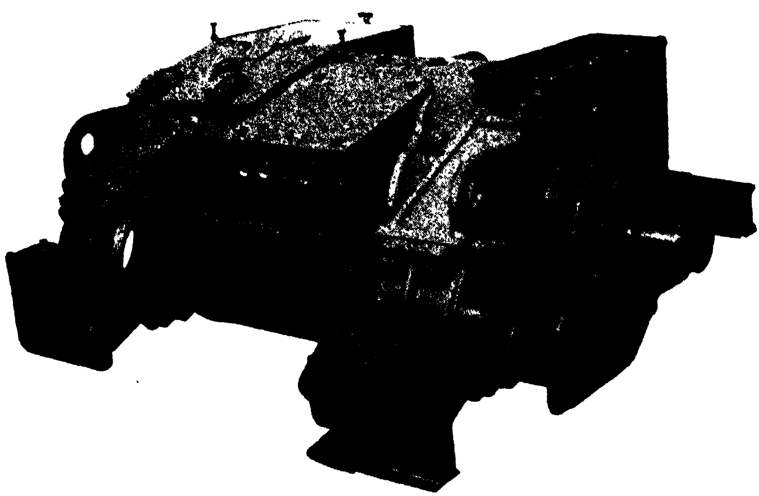


FIG. 8B. Self-ventilated traction motor (completed version of Fig. 3).

(*b*) In the self-ventilated type, air is drawn from the atmosphere and circulated through the machine by a fan mounted on the armature shaft. In order to keep the motor interior as free as possible from dust, etc., the cooling air intake may be situated in the sides

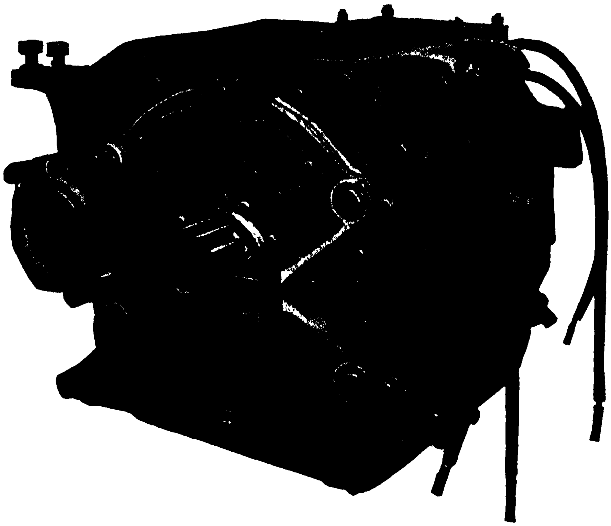


FIG. 8C. 300 h.p. force-ventilated motor from pinion end.

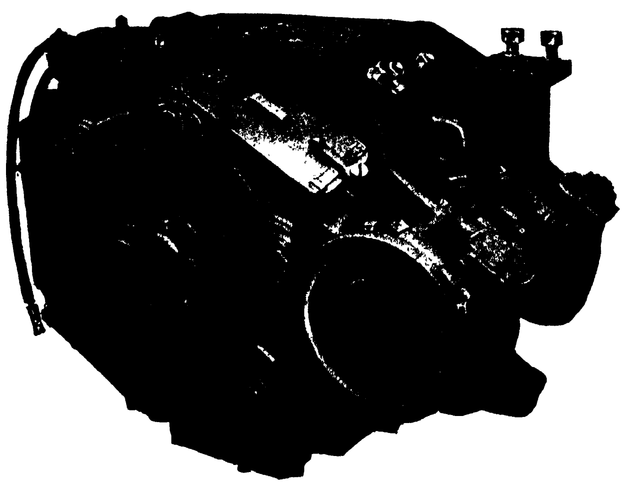


FIG. 8D. 300 h.p. force-ventilated motor from commutator end.

or roof of the locomotive and the incoming air conveyed by ducting to the motors with some form of filtration, if desired; this system is known as "Pipe ventilation."

(*c*) The forced ventilated type has the cooling air supplied by means of a blower fan driven by a separate motor or attached to some portion of the auxiliary machinery. Air is delivered through ducting, flexible where necessary, and as one blower may be used to supply two or more machines, careful design of the ducting is necessary to ensure even distribution of the coolant. Certain machines have an additional auxiliary fan fitted on the armature shaft to assist in circulation.

Of the methods outlined, it will be apparent that, for a given armature and frame size, the motor rating will be least if totally enclosed and a maximum when forced-ventilated, the latter value depending on the rate of delivery of the cooling air.

A typical armature is shown in Fig. 7, and traction motors of the totally enclosed, self and forced-ventilated types in Fig. 8.

The Single-Phase Alternating Current Traction Motor.

With single-phase alternating current power, the series commutator traction motor, as described for direct current service, is employed, but embodies a number of modifications to render it suitable for this application.

Considering a simple direct current series motor supplied with alternating current, it follows from the basic electro-magnetic principles that the flux will be approximately in phase (or synchronism) with the armature current. In consequence, a pulsating torque will be developed at the armature shaft, the resultant or mean of these pulsations providing the torque for motive power purposes. As the directions of flow of both the armature current and magnetic flux are reversed at the same instant (or very closely so), the same relative function is preserved with the result that the torque, though pulsating, is uni-directional. Due to the alternating flux, however, e.m.f.'s (technically known as transformer e.m.f.'s) are induced in the armature coils, etc.; these considerably complicate the problem of commutation and are the major reason for the differences in mechanical and electrical construction between the alternating and direct current series traction motors.

The following details are introduced into the simple series motor to render it suitable for operation on alternating current:

(*a*) Both pole-pieces and magnet yoke must be built up from laminated steel stampings, these being held, when assembled, in a rolled or cast steel frame.

(*b*) The motor must be designed to operate on a lower voltage, e.g. 200 to 400 volts, and hence will have a larger number of poles than an equivalent D.C. machine.

(*c*) The armature must be lap-wound with equalising connections and, in earlier designs, often had resistances in the coil leads adjacent to the commutator, a practice which at the present day is fast disappearing.

(*d*) A compensating winding should be situated on the stator (or frame) in order to neutralise as far as possible the alternating flux set up by the current in the armature conductors.

(*e*) The frequency of the supply must be substantially reduced below that of 50 to 60 cycles per second in general use for industrial purposes. In Europe, $16\frac{2}{3}$ cycles per sec. has been adopted as standard and, in the U.S.A., 25 cycles per second, both of which frequencies give entirely satisfactory results.

(*Note* : The German State Railways built a locomotive in 1936 with 50 cycle traction motors. While no official statement is available on its performance, to all intents and purposes this appeared quite satisfactory.)

Proceeding now to the constructional details of the A.C. series motor, in the discussion of which it should be borne in mind that the portions not detailed are, in general, identical or very similar to those employed in the D.C. machine.

Constructional Details

Stator. Both magnet yoke and pole-pieces are built up from laminated sheet steel stampings thinly coated with insulating material in a manner similar to that for armature core assemblies. In the majority of designs " salient " or projecting pole-pieces are not employed, the assembly, which is known as the stator core, having slots of various sizes cut transversally along its inner periphery to accommodate the exciting, commutating and compensating windings.

Fig. 9 shows a diagrammatic end-view of part of a stator and indicates the layout of the various windings. Note that the exciting winding produces the main pole flux and the commuta-

ting winding the interpole flux, these two windings being accommodated in the larger slots. The compensating winding is then distributed over the surface of the main pole-pieces, the slots for

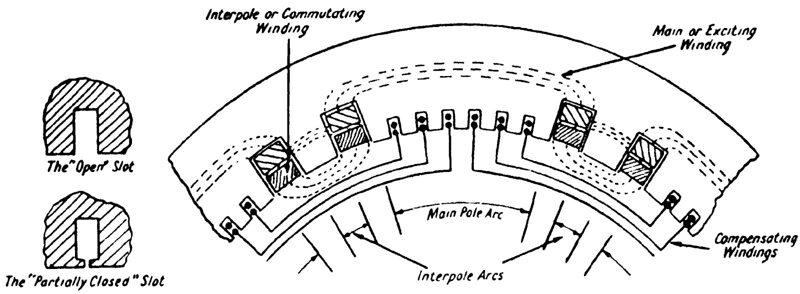


FIG. 9. Diagrammatic representation of a portion of an A.C. series motor stator, showing winding connections.

this winding being frequently of the partially closed type, the coil elements being built up in **U**-section, inserted from one end of the stator and then connected up and insulated over the joints when in position, a practice which is very common in industrial machinery.

Certain manufacturers, by the use of a large number of main poles, eliminate the need for a distributed compensating winding and enable it to be combined with the commutating winding as a single winding situated on the commutating pole. This latter, of course, is the symmetrical centre of each section of a distributed compensating winding. A stator with concentrated compensating windings is shown in Fig. 10.

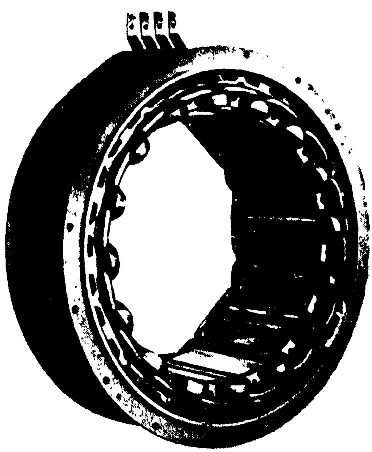


FIG. 10. Typical stator with combined compensating and commutating winding.

Field Windings. The field windings may be one of two types depending on whether open or partially closed slots are cut in the stator. With open slots, the field coils and compensating windings

used are similar in construction to those employed for D.C. motors, whilst, as outlined previously, when partially closed slots are concerned **U**-shaped winding elements are employed to build up the coils in position on the stator. The main or exciting winding consists of all main field coils grouped in a series-parallel combination ; this differs from the D.C. method of all such coils in series due to the A.C. motor operating on a low voltage and, in consequence, carrying a very heavy current unsuitable for handling by a single coil circuit. The commutating winding is similarly connected, but to improve its function it is frequently shunted by (e.g. connected in parallel with) a non-inductive resistance.

The compensating winding is so wound as to be equivalent in magnetic effect to the armature. It may be excited by external means, e.g. in series with the armature current or, alternatively, it may be short-circuited in correct phase, in which case current is induced in the winding due to the alternating flux inherent in the machine. In certain instances the traction motors may be required to operate on either direct or alternating current, in which case the A.C. type of motor must be used. External excitation of the compensating winding is essential with such a machine, as, due to certain design features, the motor will not function satisfactorily on direct current with the armature field unneutralised. Motors of this type are fitted to certain locomotives of the New York, New Haven and Hartford Railroad in the U.S.A., which operate normally from an 11,000 volt 25 cycle A.C. supply but require to pass over certain sections where a 600 volt D.C. supply is employed.

Various other methods are in use to improve commutation, amongst which are reduction of the main field strength at starting and variation of the commutating field strength with speed by means of inductive and non-inductive shunting resistances controlled by contactors and speed-relays.

Armature (or Rotor). Alternating current traction motors invariably have lap-wound armatures with equalising connections which are very similar to those of equivalent D.C. machines except that, due to the larger number of magnetic poles involved as a result of the low voltage winding, there is an increase in the number of electrical paths through the armature. In certain machines, the rotor slots are skewed a certain amount, for

example, one slot pitch in the length of the slot, this feature serving to minimize trouble due to harmonics.

Brushgear. Due to the larger number of brush holder assemblies required, up to sixteen is quite usual, it is necessary to arrange these so that they are easily accessible for maintenance purposes. This is accomplished by attaching all the holders to a steel ring which can be rotated in guides within the motor frame

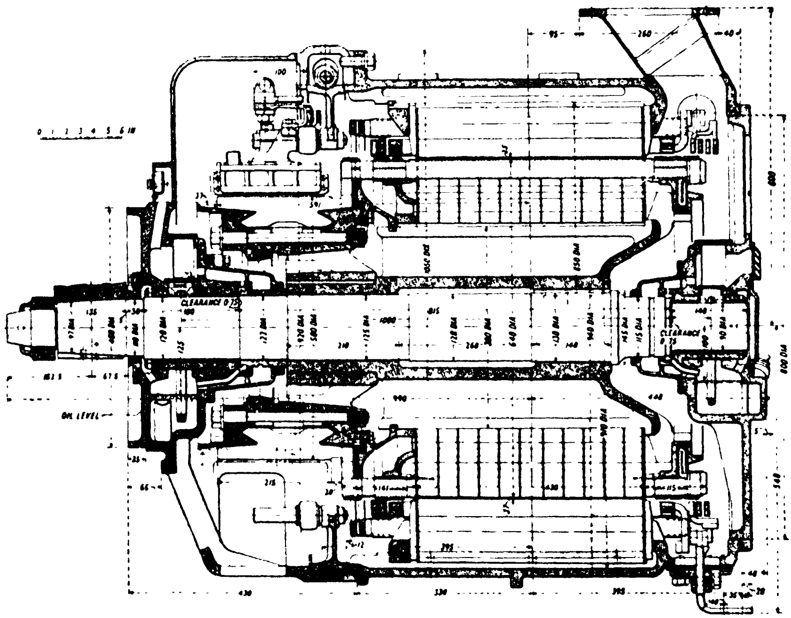


FIG. 11. Cross-section through Oerlikon 750 h.p. 435 volt single-phase commutator-type traction motor as used on 6000 and 12,000 h.p. locomotives—Swiss Federal Railways.

either by hand or by a rack and pinion drive. When in the running position the ring is locked ; for inspection purposes, the detachable cover is removed, the ring unlocked and then rotated, the various brushes being examined in succession.

Typical Machines. Fig. 11 shows a cross-section drawing of a typical 750 h.p. 435 volt single-phase traction motor as used in the 12,000 h.p. locomotive described on page 130. It is designed for frame mounting, ample access to the motor interior being provided by the large removable cover at the top.

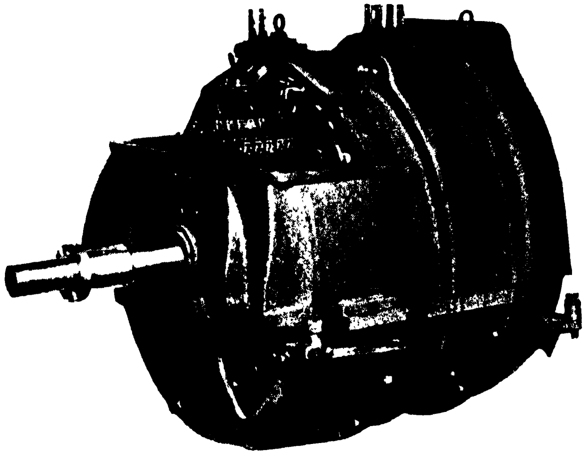


FIG. 12. 800 h.p. locomotive motor for frame-mounting (fitted to locomotives in Figs. 76, 77).

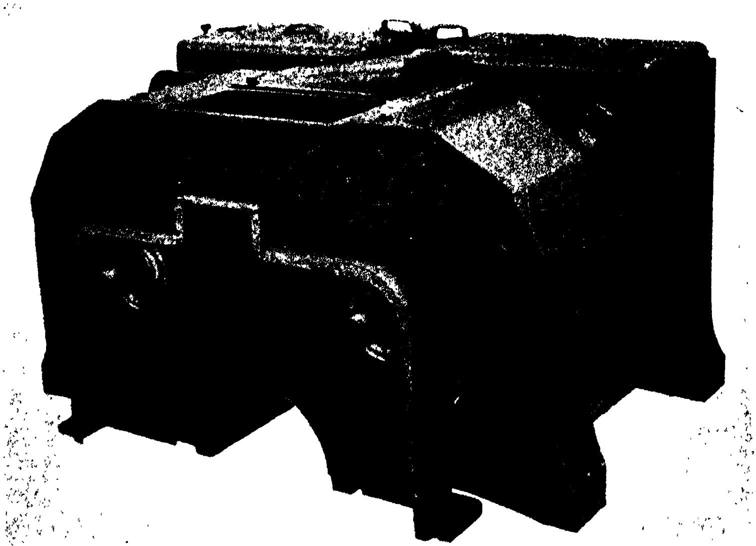


FIG. 13. Twin-armature traction motor for frame-mounting.

Fig. 12 shows a typical twin-motor. This is a 1000 h.p. Swiss machine which operates, with the two individual motor sections connected in series, on voltages up to 800 (i.e. 400 volts per armature). The two pinions drive a common gear wheel mounted on a quill shaft passing beneath the machine, see pages 105 and 136. A similar 770 h.p. machine is fitted to the famous Pennsylvania GG1 class locomotives of which 139 are in service, each with six twin-motors.

The Three-Phase A.C. Induction Motor

For traction service the induction motor is very similar in construction to the common industrial machine. As this type of motor has a constant speed characteristic it is unsuitable for use with individual axle drives as slight differences in driving wheel diameters would produce unequal loading. Collective drives of the " Scotch Yoke " and " Bianchi Link " types (see pages 141 and 150) are employed in conjunction with either slow-speed or geared motors of large output. This machine is now disappearing from modern traction practice, no locomotives having been built with such a motor in the last ten years.

Both stator and rotor are built up from laminated steel stampings and carry similar windings. The stator leads are brought out for connection to the supply and the rotor leads to three slip-rings which may be connected through brushgear to starting resistances —see Chapter Three. For further details of such motors the reader is referred to any text-book on industrial machines, as the authors feel that their application is now so limited as not to warrant further description.

Mechanical Power Transmission

The type of power transmission to be employed in any particular design of locomotive depends on several factors, amongst which are the following :

(*a*) The number of traction motors and number of driving axles.
(*b*) Relative size and rating of motors.
(*c*) Gauge of track and maximum axle-loading.
(*d*) Whether the dead weight on the road-axles must be kept to a minimum.

Several systems of drive, both individual and collective, are outlined in the following paragraphs. In addition to these, there are a number of others which deviate only in minor detail, but, bearing this in mind, readers should have no difficulty in identifying any particular drive which they may encounter in practice.

Nose-Suspension. Where hammer-blow on the track and axle-loading are not limiting factors and provided that there is one motor per driven axle, nose-suspension is the simplest form of drive obtainable. In this method the motor is supported on

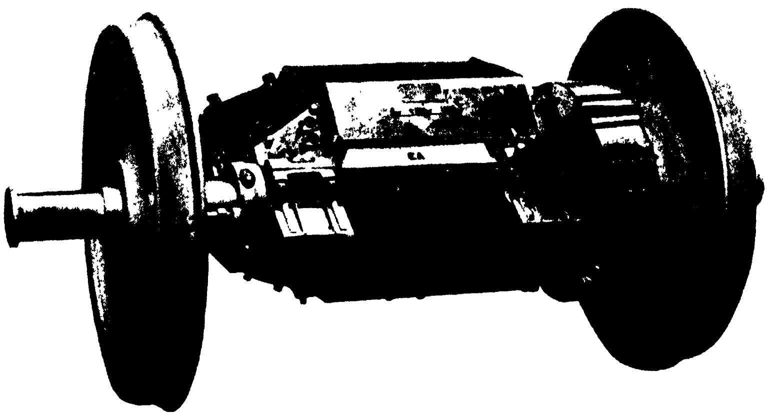


FIG. 14. Nose-suspended motor and axle.
(Emcol type motor).

bearings in which runs the road-axle, an axleway being cast and machined integral with the motor frame, with the rear of the motor carrying a nose or projection which is spring-mounted from the main or bogie underframe. Single reduction gearing is normally used, spur gears being standard in order to avoid end-thrust, although on certain larger machines twin-gears (i.e. one at each end of the armature) are employed in which case helical gears may be used, if desired.

For a considerable number of years the bogie-mounted nose-suspended traction motor was not considered suitable for operation at speeds much in excess of 60 m.p.h. and, consequently, high-

speed passenger locomotives were always equipped with some form of individual axle drive from motors mounted in the main frame. During the past few years, however, nose-suspended motors mounted on bogies have become standard practice on all American diesel-electric locomotives both for passenger and freight service, and have operated quite successfully at speeds up to 120 m.p.h., a fact which will doubtless have its effect on future design.

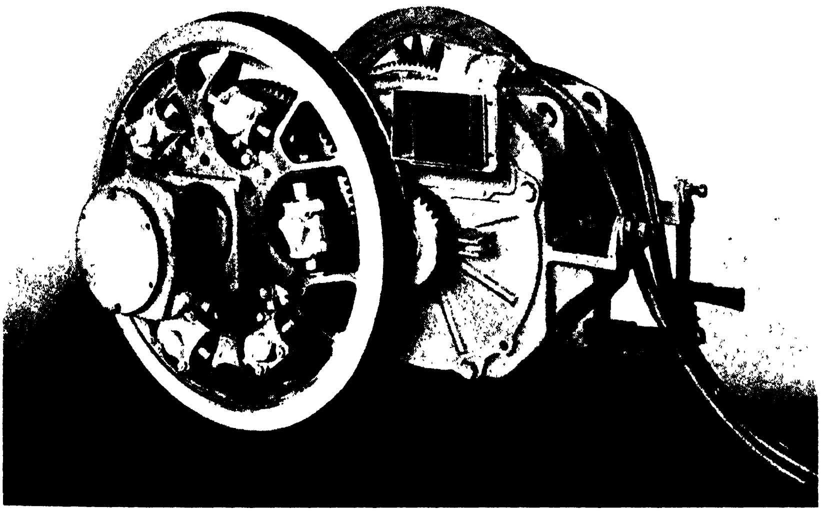


FIG. 15A. Quill and cup drive—frame mounted motor (as fitted to French main-line diesel-electric locos).

Individual Axle-Drives. Where, in a locomotive design, it is desired to have the traction motors rigidly mounted on the main frames with some form of flexible drive to allow for axle movement, one of the following types of drive or a derivative from it must be employed.

In the " Quill and Cup " drive, the motor may be mounted either above the road-axle, or, if desired, adjacent to it in a manner very similar to that used with nose-suspension. (When twin-motor units are employed, these are usually mounted saddle-wise above the axle.) A large axleway is cast integral with the

motor frame and carries in its bearings a hollow quill-shaft which is gear-driven from the armature. Through the centre of this quill-shaft passes the road-axle, ample clearance being allowed to permit movement of the latter with spring-deflection. The tractive power is transmitted direct from the quill-shaft to the driving wheels by means of spring-cups attached to the quill flanges which press on rubbing plates attached to the spokes of the wheels themselves.

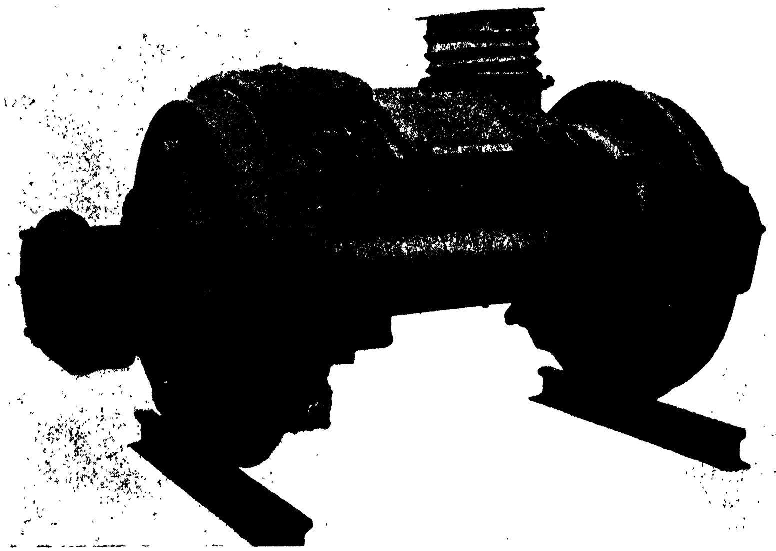
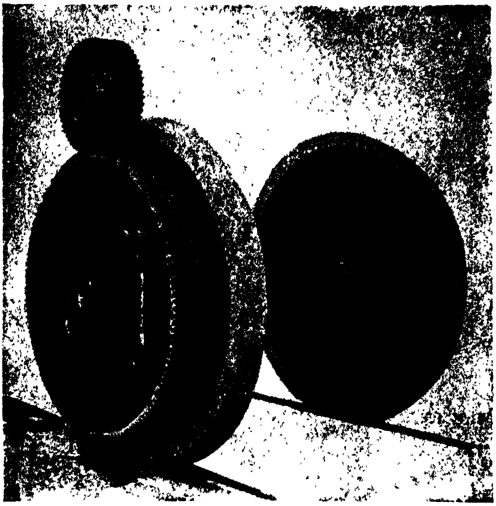


FIG. 15B. Sécheron quill and spring drive—motor mounted on bogie frame.

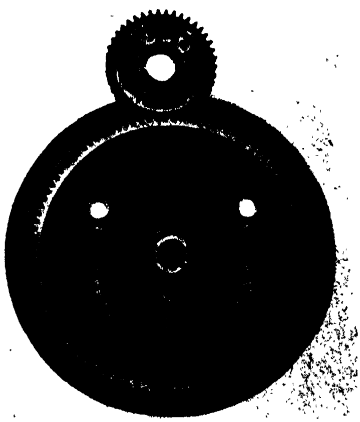
The " Sécheron " spring-drive is very similar to the quill and cup, differing only in the method of transmitting the torque from the quill to the driving wheels. Instead of cups and rubbing plates, a system of springs attached to quill-shaft and road wheels is substituted.

Fig. 15 shows examples of these two drives, in each case the motor being slung alongside the axle and employing twin gears (i.e. one set of gears at each end of the armature shaft).

The " Buchli link " drive, fitted extensively by Messrs. Brown-Boveri, is employed in connection with motors fitted above and parallel to the road-axle. In this system, a spring pinion which



(i)



(ii)

FIG. 16. Buchli link drive (with close-up of spring gear).

is mounted on an extended armature shaft, is arranged to drive a gear wheel attached by flexible links to the outside of the driving wheel (Fig. 16). Large numbers of locomotives of the Swiss Federal Railways have this type of drive, this being easily recog-

nisable by the large gear-enclosing cases which almost conceal the driving wheels on one side of the locomotive—see Figs. 70, 76 and 77.

Messrs. Brown-Boveri have recently developed a new spring-disc drive for bogie-mounted motors—Fig. 17.

An entirely different system has been developed in the Swiss Locomotive and Machine Works' "Winterthur Universal Drive." Two motors per axle are necessary, these being mounted in line parallel to each axle and with their driving pinions on the centre-

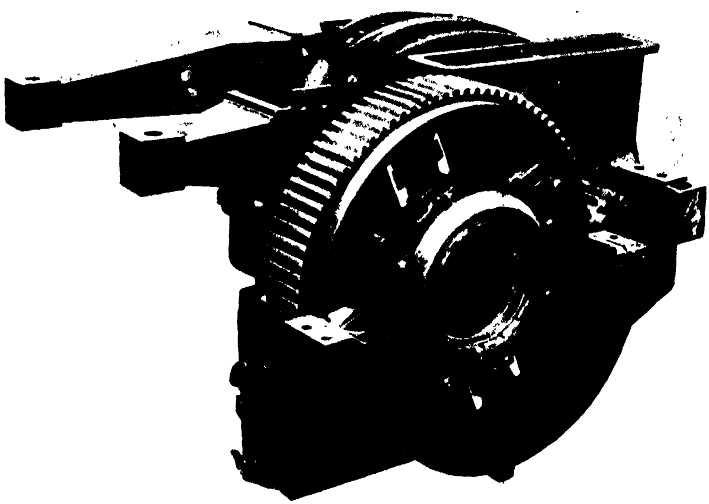


FIG. 17. The Brown-Boveri spring-disc drive.

line of the locomotive. From these pinions, a double-reduction drive transmits the torque to a gear, flexibly mounted on sliding blocks attached to the road axle, the arrangement being very similar in operation to the familiar "Oldham coupling." A cross-sectional diagram of the drive as applied to a 12,000 h.p. locomotive and a view of the flexible gear are shown in Fig. 18.

Collective Drives. When several axles have to be driven from only one or two large traction motors, some form of collective drive must be employed. All forms of collective drive necessitate the driving wheels to be coupled together in one or more sections, as in steam locomotive practice, and, due to the lubrication and oscillation troubles incurred by the heavy reciprocating parts,

particularly at higher speeds, modern electric locomotive design does not employ these cumbersome systems on other than heavy freight and shunting locomotives.

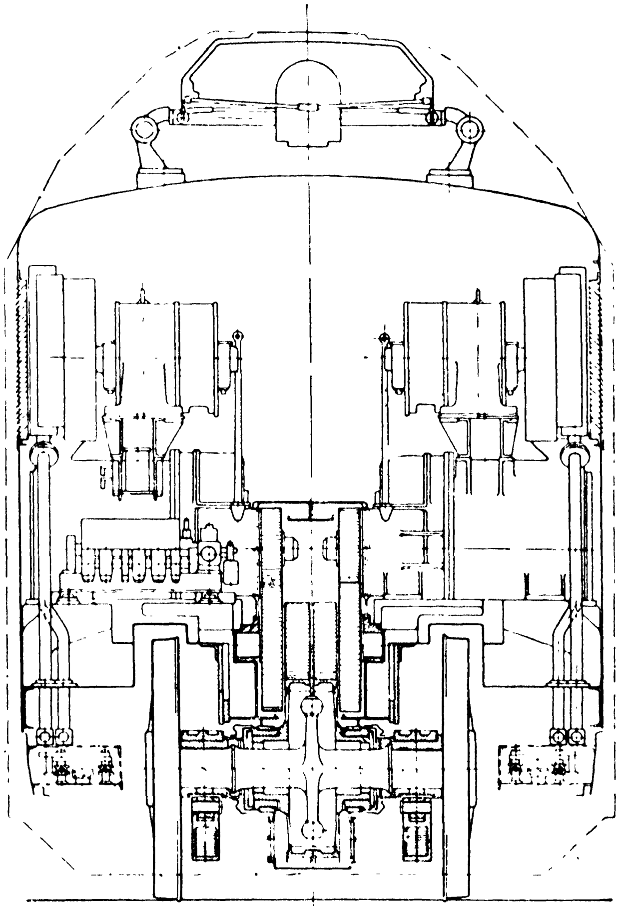


FIG. 18 (i). Cross-section through Swiss 12,000 h.p. locomotive with Winterthur universal drive.

The " Jackshaft-Side rod " drive follows closely on steam locomotive practice, the coupled wheels being driven by connecting rods attached to cranks, one at each side of the main frame. These cranks are mounted either directly on the armature shaft or, more usually, on a jackshaft driven by the motor through single or

double-reduction gearing. In certain circumstances, two motors are employed to drive a common jackshaft, as in the freight locomotive described on page 114.

A novel system of drive was developed by the late Dr. de Kando and applied to both freight and passenger locomotives on the Hungarian State Railways. This is known as the " Kando rod " drive and functions with two motors or one motor with an auxiliary or dummy shaft. At each end of the armature shafts, cranks are

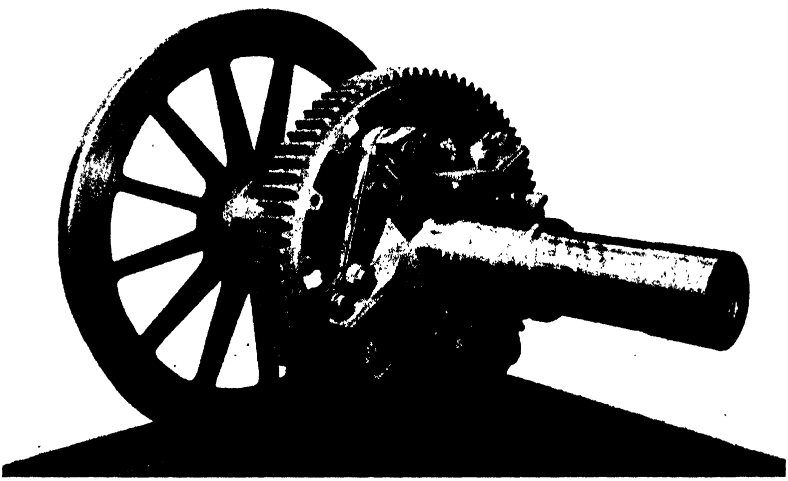


FIG. 18 (ii) View of flexible gear with cover and half-wheel removed. Swiss 12,000 h.p. locomotive with Winterthur universal drive.

attached which are connected to two frames, one attached and pin-jointed to the driving wheel coupling rods at each side of the locomotive. The system is clearly shown in Fig. 100 installed on one of the aforementioned passenger locomotives.

Two methods have been extensively employed on the three-phase locomotives of the Italian State Railways where the majority of locomotives have two large slow-speed induction motors suitable for direct drive without the use of gearing. The earlier method used was the " Scotch Yoke " in which a large triangular frame is attached to cranks on each of the two motor shafts, this frame then driving the connecting rod assembly through sliding blocks and

crankpins. As a considerable amount of lubrication trouble was experienced, together with a large consumption of oil, this drive was superseded on later designs by the " Bianchi link " system, employing a pin-jointed link framework which is much more satisfactory in operation. Both systems are shown in the illustrations of locomotives on pages 141, 150.

Examples of the majority of these drives are given in the chapters describing the completed locomotives and, in addition, the appendix tables detail the drive employed on each of the locomotives listed. The reader will hence be able to form his own ideas as to the popularity and limitations of each type.

Motor Rating. The following definitions and tables show the standards concerned when detailing the rating of a traction motor.

The " one-hour rating " is the output at the motor shaft measured in either horsepower or kilowatts which the motor can carry for one hour on a stand test with the ventilating system as in service without exceeding the temperature limits set out in the accompanying table.

The "continuous rating" of a motor is the output at the motor shaft measured in either horsepower or kilowatts which the motor can carry for an unlimited period on a stand test with the ventilating system as in service without exceeding the temperature limits set out in the table.

The tables on p. 32 set out both American and B.E.S.A. standards. Certain other qualifications are imposed for which the reader is referred to the respective publications.

Tables of Motor Rating

ITEM	Type of enclosure	Method of Determination of temperature	Limiting Temperature Rise °C			
			One-hour rating		Continuous rating	
			*A	*B	*A	*B
Armature and field windings	Ventilated	Resistance	100	120	85	105
		Thermometer	80	95	65	80
	Totally enclosed	Resistance	110	130	95	115
		Thermometer	90	105	75	90
Cores and mechanical parts in contact with or adjacent to insulation	Ventilated	Thermometer	90 B.E.S.A. 80 A.I.E.E.	95	65	80
	Totally enclosed	Thermometer	95 B.E.S.A. 90 A.I.E.E.	105	75	90
Commutator	Ventilated	Thermometer	95	110	80	95
	Totally enclosed	Thermometer	105	120	90	105

*A denotes " Class A " insulation, which is cotton, silk, paper and similar organic materials when impregnated ; also enamel as applied to conductors.

*B denotes " Class B " insulation, which is inorganic materials, such as mica and asbestos in built-up form combined with binding substances. If Class A material is used in small quantities in conjunction for structural purposes only, the combined material may be considered as Class B, provided that the electrical and mechanical properties of the insulated winding are not impaired by the application of the temperature permitted for Class B material.

CHAPTER THREE

CONTROL GEAR

In the control of any type of locomotive it is necessary to provide suitable means for the obtaining of a reasonably smooth acceleration without violent jerks or " snatches " likely to fracture couplings, etc., and also a method of regulating the speed and power input to the motors to allow for variation in types of train, duty and speed restriction. In consequence, it is most undesirable to switch the traction motors directly on to the supply-line, as, quite apart from the terrific mechanical stresses this would impose on the motors themselves and the large current rush involved, the initial start would be very violent indeed and would result in severe slipping due to the limited adhesion available. Different methods of overcoming these difficulties are employed according to whether the locomotive is to operate from a direct or an alternating current supply and these methods are dealt with separately in the following sections.

Direct Current Motor Control

The method employed to obtain a reasonably smooth accelerating torque from a D.C. motor is that of inserting a suitable resistance into the motor circuit at starting and then cutting this resistance out progressively in small sections as the motor accelerates. This has the effect of limiting the current and hence the torque and tractive effort developed on each step of this sequence. The actual value of resistance and number of sections or steps employed depends upon several factors, these including the type of service, supply voltage, number of motors and their relative inter-connection. As it is not normal practice to attempt to design this resistance to be capable of carrying the motor current continuously, only one running position is obtained with this simple scheme, i.e. when the motor has reached its full speed with the resistance cut out of circuit.

Series-Parallel Control. From the method of resistance control outlined above, it will be seen that no provision is made for varying the resultant motor speed and output. The simplest

system in use which provides two such running positions is known as series-parallel control and is the basis of the control system employed on the majority of D.C. locomotives. Acceleration is carried out in two stages, the two motors are first connected in " series " (i.e. so that the line current passes through each in turn and only half the applied voltage is impressed on each machine). They are then accelerated by progressive elimination of a number of resistance steps until a balancing speed and output is reached,

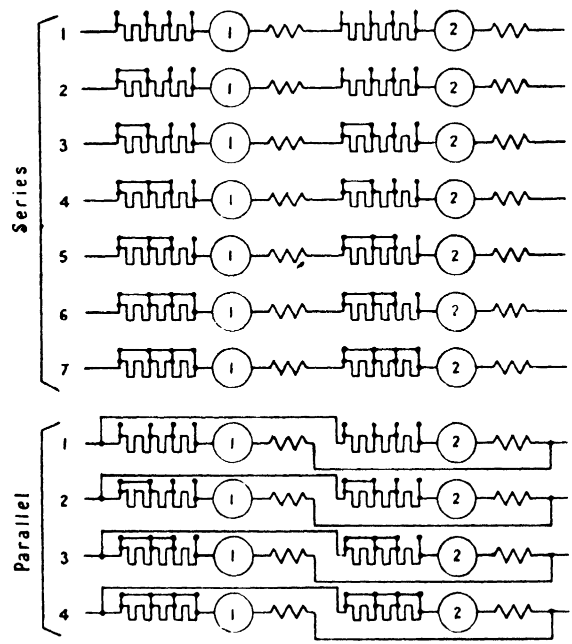


FIG. 19. Sequence of connections—series-parallel control.

this corresponding to the lower speed running position. The second stage is reached when the motor connections are changed to " parallel," in which state each motor is independently connected to the supply with a starting resistance in its circuit. Acceleration is then continued by the resistance elimination method up to the second balancing speed and running position. It should be borne in mind, of course, that, in both of these running positions, the motor speed is dependent on the load, the inherent characteristic of this type of machine. The sequence of connections of a simplified starting circuit of this type are shown in Fig. 19.

Seven steps are provided with the series connection and four with the parallel, but the latter may be sub-divided, if required, to provide seven steps by cutting one resistance step out of each motor circuit alternately.

Transition. The period during which the motor connections are changed from the series running position to the first step with parallel connections is known as "transition." Various methods of accomplishing this change are employed, these being designed

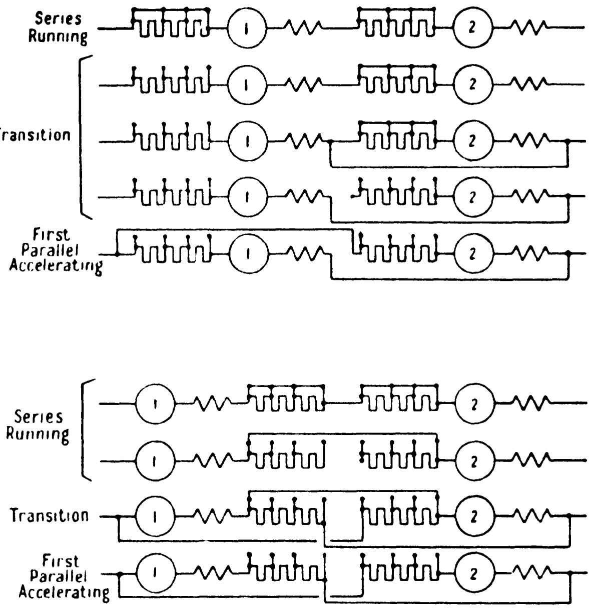


FIG. 20. Methods of transition.
(i) Shunt. (ii) Bridge.

to maintain, as far as possible, a reasonable tractive effort during the transition period. Two methods are in general use; these are "shunt" transition and "bridge" transition, the sequence of connection changes with each of these methods is outlined in Fig. 20.

It will be noted that in the shunt method the starting resistance, or some portion of it, is first re-inserted into the circuit, next, No. 2 motor is short-circuited, an action which brings No. 1 motor into parallel connection, finally, No. 2 motor circuit is isolated from No. 1 and, with its resistance re-inserted, connected

direct to the supply. This method results in a considerable reduction of tractive effort during the transition period due to the short-circuiting of No. 2 motor; however, it is preferred by most designers, as arcing on the rupturing of the various connections is minimised.

Bridge transition requires the starting resistance to be divided into two halves, both of which are inserted between the motors. Due to the continuous application of power to both motors throughout the process, suitable design of the starting resistance enables the tractive effort to be maintained throughout. However, difficulty is encountered due to excessive arcing on rupturing the series link (see diagram) and this condition must be catered for in the design of the equipment.

Contactors. In order to make and break the necessary connections in the circuit, some form of switching device is necessary which is capable of carrying and interrupting the various currents involved. The method universally adopted for this purpose utilises some form of contactor. A contactor consists essentially of a fixed contact, rigidly attached to, but insulated from, the framework of the contactor, and a moving contact which is moved over a travel of ½″ to 1″ by the various means described in a later paragraph. In the closed position, a certain pressure is applied to the bottom contact in order to keep the heating of the contacts down to a minimum, usually about 40°C. rise on the continuous current rating. The operation of closing is so designed that the tips of the two contacts touch first, after which the moving contact rolls or " wipes " to the rear or heel of the fixed contact for the current carrying period. In order to provide this wiping action and the necessary contact pressure, the moving contact is mounted so that its tip will touch some time before the closing mechanism has fully operated. The additional travel then obtained is used to roll the moving contact over to its heel and to compress a spring between the contact arm itself and the closing mechanism, an action effectively demonstrated in Fig. 21 (*a*).

Before dealing with the methods adopted for closing mechanisms, it is preferable to outline the means adopted to rupture the arc which forms between the contacts when they are opened. To expel this arc away from the contacts and so rupture it, use is made of the basic principle that a current carrying conductor placed in a magnetic field is acted on by a force tending to move it

in a direction at right angles to its own line of direction and to that of the magnetic flux. The current passing through the contacts is passed around a coil, which, in the case of a main circuit contactor, consists of from five to twenty turns of copper strip situated above the fixed contact, and the magnetic field so pro-

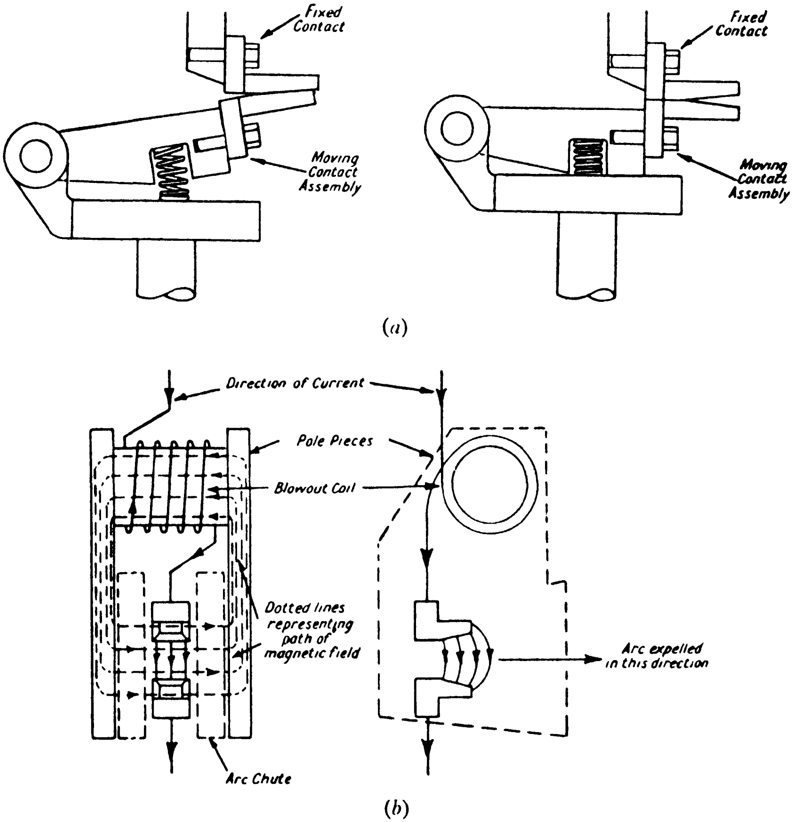


FIG. 21. Diagrammatic representations of arrangements for (*a*) wiping action and contact pressure and (*b*) arc rupturing.

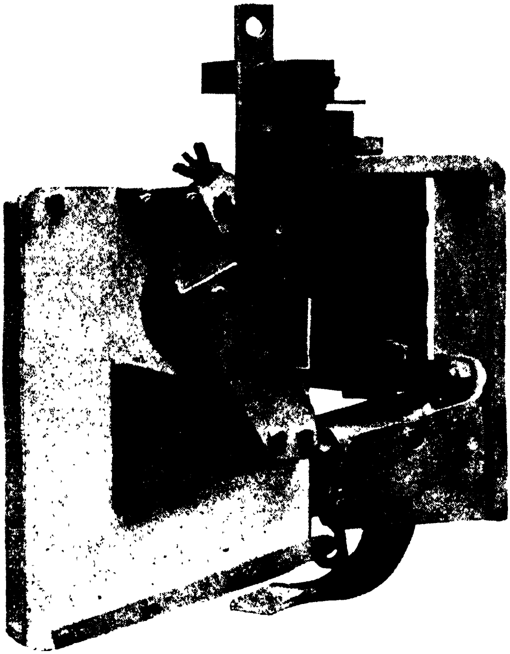
duced is transferred to the contact area by steel pole-pieces. By winding this coil in the correct direction the magnetic field produced across the contact gap will be of such a direction that, in the event of an arc forming, it will be ejected away from the contact tips and so extinguished. This action is shown diagrammatically in Fig. 21 and the " blowout coil " assemblies, as these are called, are clearly visible above the fixed contacts in the

various contactors illustrated later in this chaper. To reduce burning still further, it is customary to fit an arc-horn which extends beyond the end of each contact tip, and a blowout shield to prevent the arc from striking back on to the blowout coil itself. Finally, the contacts, arc-horns, etc., are enclosed in a heat-resisting box, open at front and rear, in order to confine the arc and to protect the pole-pieces, between which this " arc-chute," as the assembly is called, is designed to fit. In certain designs of contactor, the whole arc-chute assembly, including pole-pieces, may be removed in one unit to facilitate access to the contacts for cleaning and other maintenance purposes.

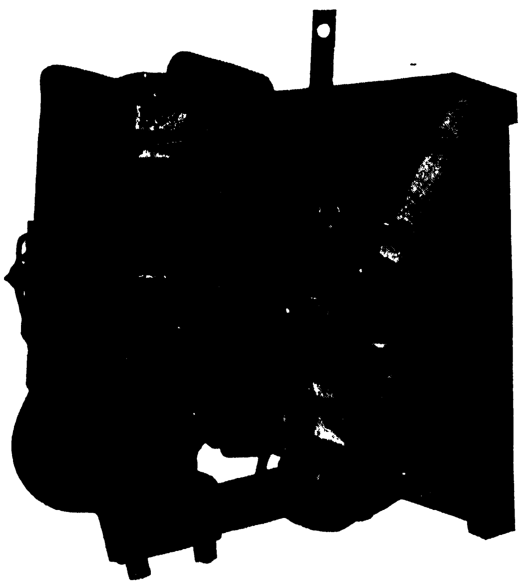
The closing action of the moving contact may be obtained by one of three differing means: electro-magnetically, electro-pneumatically, or by the operation of a cam and roller mechanism.

An electro-magnetic (E.M.) contactor is one in which the contacts are brought together as a result of magnetic action. A small actuating current is passed around a coil consisting of several thousand turns of fine gauge copper wire. This coil has a central soft iron core passing through it and is fitted to the contactor frame in such a manner as to provide a magnetic circuit through the core and frame to a clapper (or armature) carrying the moving contact. In the open position of the contactor a gap of ½" to 1" separates this clapper from the lower end of the core, and when the actuating current is applied the magnetic field bridging this gap causes the clapper to be attracted to the core, so raising the moving contact. An alternative form to this arrangement is obtained by using a divided core with the lower half attached to the moving contact arm. Energising the coil produces a force of attraction between the two halves of the core resulting in the raising of the lower half with its attachment. These two types of contactor are known as " clapper " and " plunger " types, illustrations of each being shown in Fig. 22.

The most popular form of contactor amongst locomotive engineers is the electro-pneumatic (E.P.) type, known as the unit-switch, in which the moving contact is attached to, but insulated from, a piston moving in a cylinder, the assembly being spring-loaded in the open position. The piston is raised by compressed air admitted and released under the control of an electro-magnetic air valve, this consisting of the necessary valves opened or closed by a valve-spindle operated by means of a clapper-type electro-



(i)



(ii)

FIG. 22. Clapper and plunger type electromagnetic contactors.

magnet assembly. In the "open" or "off" positions, the cylinder is connected to the exhaust port in order to discharge to atmosphere any leakage through the closed supply valve and so ensure that the contactor cannot close with this condition. Energising of the valve coil depresses the spindle, connects the air supply to the cylinder and raises the piston to close the main contacts. On de-energising, the air in the cylinder is released to

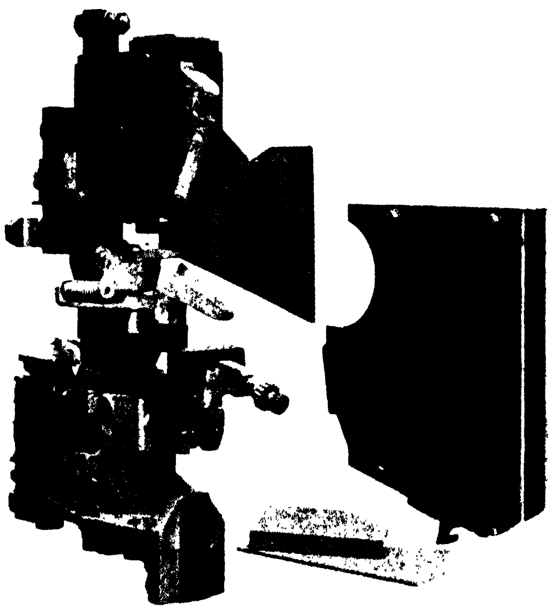


FIG. 23. Lightweight electro-pneumatic contactor with arc chute and one pole-piece detached.

atmosphere and the contacts open due to the spring-loading of the piston.

The cam-operated contactor in its simplest form has a roller attached to the lower side of the moving contact arm, and this roller runs on an insulated cam mounted on a common cam-shaft. The method of cam-insulation varies; in some cases the cam roller is insulated from the contact arm; alternatively, the cam itself may be made of insulating material or a steel cam may

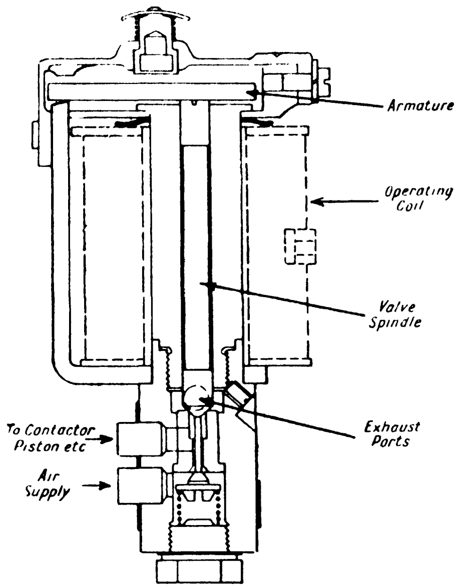


FIG. 24. Magnet valve.

be employed mounted on an insulated camshaft. A typical cam-contactor is shown in Fig. 25, with a group assembly of cam-contactors for motor drive in Fig. 26 on p. 42.

Movement of the camshaft may be carried out in three ways :

(*a*) Direct from the controller handwheel through a reduction gear, a device very popular in Switzerland.

(*b*) By an electric motor of ½ to 1 h.p. driving the shaft through a double-reduction worm-gear.

(*c*) By an air engine consisting of a double-acting piston with a stroke of about 12 inches enclosed in a cylinder with an electro-magnetic valve at each end. The two valves function so as to control the admission of air to one side of the piston and exhaust from the other. The camshaft is rotated by means of a rack and pinion and is arrested at points in its travel when required by manipulation of the exhaust valve.

With all types of contactor it is customary to feed the current passing to the moving contact through a flexible braid copper connector in order to avoid overheating due to current passing through bearings and other movable parts.

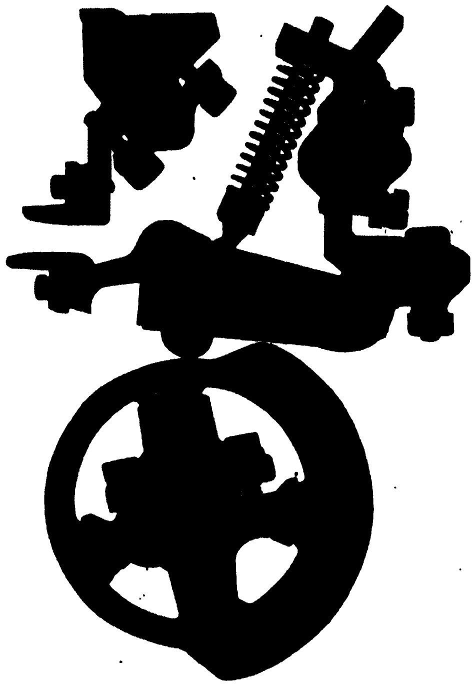


FIG. 25. Cam-contactor element showing fixed and moving contacts and cam.

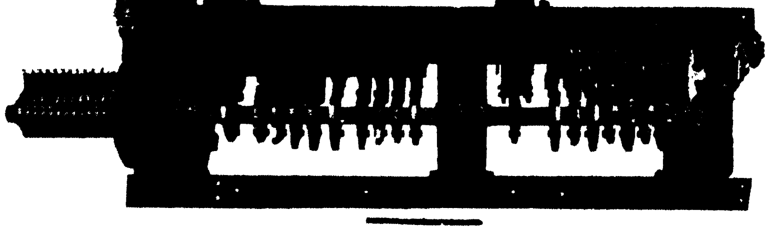
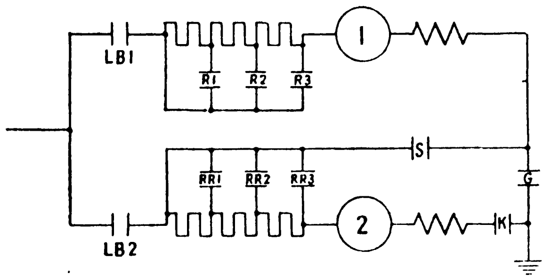


FIG. 26. Camshaft-contactor group assembly with electric motor drive.

Application of the Contactor to Series-Parallel Control

The diagram (Fig. 27) shows a series-parallel circuit for the control of two motors using contactors for connection of the circuit to the supply, for grouping the motors in their two combinations and for cutting out the various sections of starting resistance.



NOTCH		LB1	LB2	R1	R2	R3	RR1	RR2	RR3	S	K	G
OFF												
SERIES	1	●								●	●	
	2	●		●						●	●	
	3	●		●			●			●	●	
	4	●		●	●		●			●	●	
	5	●		●	●		●	●		●	●	
	6	●		●	●	●	●	●		●	●	
	7	●		●	●	●	●	●	●	●	●	
TRANSITION		●					●	●	●	●	●	
		●					●	●	●	●	●	●
		●									●	●
PARALLEL	8	●	●								●	●
	9	●	●	●							●	●
	10	●	●	●			●				●	●
	11	●	●	●	●		●				●	●
	12	●	●	●	●		●	●			●	●
	13	●	●	●	●	●	●	●			●	●
	14	●	●	●	●	●	●	●	●		●	●

FIG. 27. Simple series-parallel control scheme using contactors. (Chart shows contactors closed on each controller handle position.)

Starting from the off position, the closing of LB1, S, K, connects the two motors in series with all resistance in circuit. Acceleration is then obtained by the cutting out "step by step" of the various portions of starting resistance, this being carried out by closing the contactors R1, RR1, R2, RR2, R3, RR3 in this sequence until, when all are closed, the series-running connection is obtained. (*Note*: At this point the following contactors are closed: LB1, S, K, R1, R2, R3, RR1, RR2, RR3.) Proceeding, shunt transition is then carried out by the following sequence:

1. Contactors R1, R2, R3, RR1, RR2, RR3 open.

2. Contactor G closes.
3. Contactor S opens.
4. Contactor LB2 closes.

Contactors LB1, LB2, G, K are now closed and further acceleration is then obtained by again closing R1, RR1, R2, RR2, R3, RR3 contactors in this order. Electrical interlocking between contactors is necessary and is utilised to ensure correct operation and protection against faults.

Reversers. Two means are available for reversal of the direction of rotation of a series traction motor, viz. reversal of

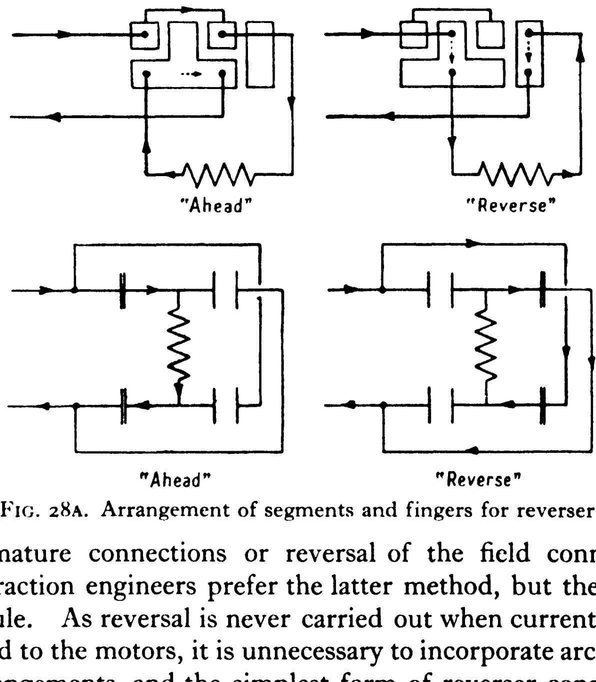


FIG. 28A. Arrangement of segments and fingers for reverser.

the armature connections or reversal of the field connections. Most traction engineers prefer the latter method, but there is no fixed rule. As reversal is never carried out when current is being supplied to the motors, it is unnecessary to incorporate arc-rupturing arrangements, and the simplest form of reverser consists of a drum or cylinder which makes contact with a series of fingers so as to give the two requisite directions. Fig. 28A shows the simple segment arrangement for one motor and it will be noticed that the direction of current flow through the field is the opposite in the reverse position to that in the ahead. With a series-parallel motor circuit two such sets of segments and fingers are required, one for each motor, and these are mounted together on a common shaft.

Certain manufacturers and operating companies prefer contactor type reversers, in which case the segments and fingers are replaced by four sets of fixed and moving contacts operated by cams mounted on a common shaft (lower part of Fig. 28A).

The reverser is moved from one position to the other and vice-versa by means of a crank attached to the shaft, this crank being operated by one of the following means :

(*a*) Two plunger-type electro-magnets, one or other of which is energised according to the position required.

(*b*) Compressed air, using a double-acting piston enclosed in a cylinder, air being admitted to the requisite side of the piston by two electro-magnetic valves, one at each end of the cylinder.

(*c*) Direct linkage from the main controller reverse handle, this being used on the small types of locomotive only.

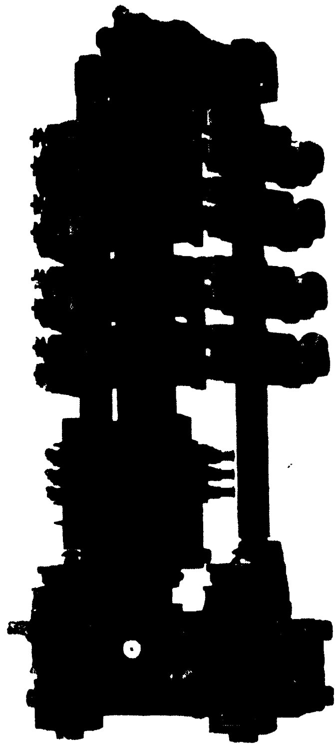


FIG. 28B. Typical electro-pneumatic cylinder type reverser.

On reversers operated indirectly (i.e. by methods (*a*) and (*b*)), it is necessary to fit electrical " proving " interlocks which complete circuit only when the reverser is in a running position and, therefore, prevent the application of power to the motor circuit, should the reverser fail to function.

Protection Against Overload. Protection of the equipment against overload due to over-rapid acceleration, excessive train-load and faults in the apparatus and circuits may be obtained by the inclusion in the equipment of a circuit breaker, an overload relay or both.

The circuit breaker is essentially some form of contactor or

switch equipped with a tripping mechanism which will cause it to open at some pre-determined current (e.g. 50 per cent. above the maximum normal current). Tripping is carried out by an electromagnet unit which releases the retaining latch, the rate of operation and current rupture being frequently arranged to be of sufficient rapidity that the circuit is interrupted before the current becomes excessive.

FIG. 29A. Overload relay.

An overload relay consists of a clapper-type electro-magnet with a power coil of several turns carrying the main current, the clapper being held open by a spring, adjustment of whose tension enables the tripping value of the relay to be varied. On the current reaching the set value, the magnetic attraction overcomes the spring-tension, the clapper closes up to the core and in doing so interrupts the circuit of a series of auxiliary contacts, this latter action being arranged to trip the line-breakers (e.g. LB1, LB2, in Fig. 27) and so arrest the flow of current. After opening, the relay latches and remains there until reset by a small auxiliary electromagnet fed from the control switch in such a way that the relay cannot be reset until the master controller is set to the "off" position.

A third relay which assists in the prevention of overload is the "No-current relay." This is similar to an overload relay, but has an increased number of turns on its coil, and is arranged to close at a low current (e.g. 25 to 50 amps). Auxiliary contacts are fitted which make it impossible for the sequence to proceed beyond the first series notch until the relay has closed due to current flowing in the circuit. In the event of a supply failure,

the relay drops out ; this results in the opening of all contactors, these being interlocked with the line-breakers, and hence makes it necessary for the driver to move the controller back to the " off " position before he can again apply power.

Typical overload and no-current relays are shown in Figs. 29A, 29B.

Auxiliary Relays. Several types of auxiliary relay are used in electric locomotive equipment. In general, these consist of an

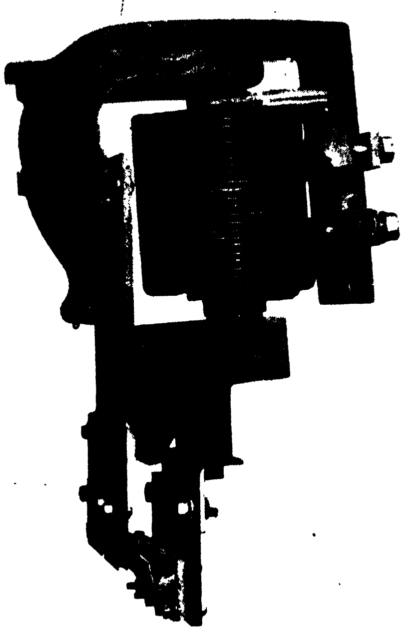


FIG. 29B. No-current relay.

electro-magnetic assembly, of either the clapper or plunger type, carrying a series of contacts fingers or discs for making and breaking the circuits. A typical relay is shown in Fig. 29C. Electro-pneumatically operated relays are sometimes employed, but, in general, are unnecessary and unadvisable due to the additional maintenance they require.

Field Reduction. The operation of " tapping " or " shunting " the motor field to obtain an increase in the number of running

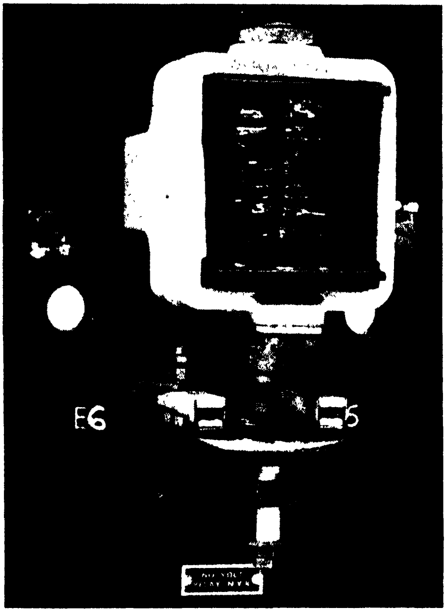


FIG. 29C. Plunger type auxiliary relay.

positions or speeds may be carried out by either electrically-interlocked unit-switches or by a cam-operated contactor group similar in construction to a reverser of this type but incorporating blowout arrangements at the contacts.

Main Starting Resistance. The starting resistance for an electric locomotive is divided up into a number of separate boxes or sections for convenience of handling and mounting in the frames. Each box contains a number of cast-steel resistance grids mounted on insulated bars, the bars being held by two end-plates. The grids in any one box are all connected in series by alternate spacing with mica and steel washers, terminals being provided on the grids at each end and at the necessary tapping points in the resistance assembly.

With the exception of the auxiliary relays, all the equipment described so far handles the main motor current and must be insulated to carry the line voltage. Operation of all contactors and relays, etc., is carried out by the control circuits operating on voltages between 50 and 200, a feature which considerably reduces

the insulation required on the various items of equipment involved, chief one of which is the master controller.

Master Controller. The master controller of a locomotive provides the means of energising the various contactors and relays etc., in the correct sequence for the operation required. In its simplest form it has two operating handles, one controlling the direction of motion with three positions : " Forward," " Off," " Reverse," and the other, the acceleration of the locomotive by

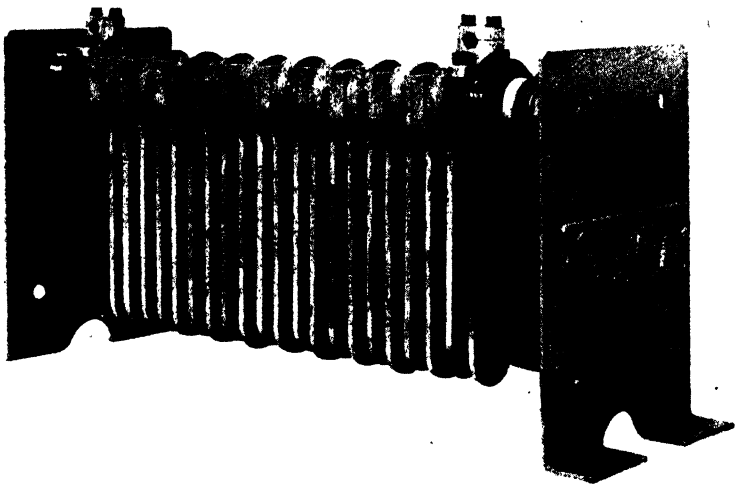
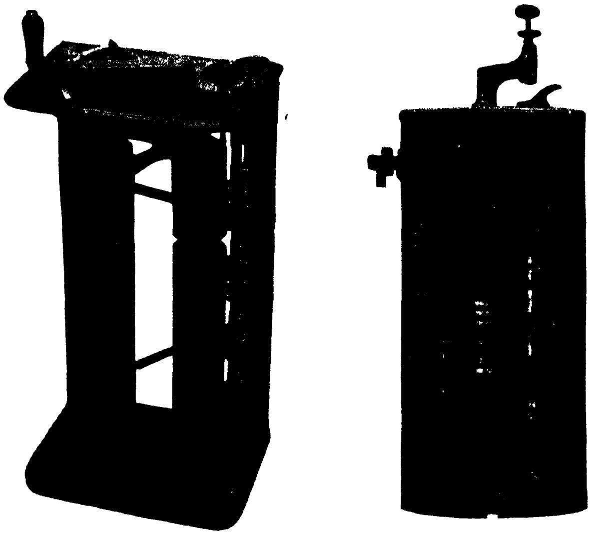


FIG. 30. Main starting resistance box.

control of the resistance and motor connection contactors. The interior of the controller has two insulated drums or cylinders, each rotated by its appropriate operating handle. On the circumference of these drums are attached copper segments which make contact with small " fingers " mounted on an insulated bar at one side of the controller, these fingers being connected to the various contactors and relay circuits, which are, consequently, energised according to the positioning and relative inter-connection of the segments on the drum.

In actual practice many variations of the above outline are encountered, e.g. :

(*a*) When a large number of accelerating steps or notches are employed, a separate drum and control handle may be provided for selection of the motor combination (series, parallel, etc.), the main accelerating handle being returned to the first notch during transition. In certain cases this combination drum may be combined with the reverse drum, so giving the latter five positions,



(*a*) (*b*)

FIG. 31. Typical master controllers.

viz.: " Forward parallel," " Forward series," " Off," " Reverse series," " Reverse parallel," although the last of these is sometimes omitted as unnecessary. Further, when electric braking is to be employed, the brake control cylinder and its handle are also frequently incorporated in the controller.

(*b*) The drum with segments attached is sometimes exchanged for special castings to which the segments are screwed, these castings being clamped to a square insulated shaft to whose upper extremity is attached the appropriate control handle.

(*c*) Small cam-operated contacts are also becoming popular, each consisting of two contacts built into a common terminal bar and arranged so that the circuit is closed by bridging the contacts with a metal strip attached to a cam-roller which is actuated by a cam carried on the main shaft.

Control Schemes. Fig. 32A shows the power circuits for a four-motor 1500 volt locomotive, as built for the New Zealand Government, see page 100. The motors are wound for 750 volts and each pair is connected in permanent series, series-parallel control of the two groups thus formed being employed using electro-pneumatic contactors. In the series position, all four motors are connected in series and are re-grouped as two pairs in series-parallel for the parallel accelerating sequence. By the use of two tappings on the motor fields, additional running positions are obtained with both series and parallel connection, this giving a total of six such positions. The power chart provided gives the sequence of closing of the contactors and it will be noted that there are 14 accelerating steps and 2 reduced field positions in the series connection followed by 5 accelerating steps and 2 reduced field positions with the parallel connection, this making a total of 23. The controller is of the two drum type, one cylinder for acceleration and one for reversal, as shown in Fig. 31.

Shunt transition is employed, two unit switches in series being fitted in the series connecting link (S1, S2) and in each line-breaker position (LS1, LS2, LS3, LS4), this being adopted due to the high-voltage supply. Three further points are worthy of mention :

(*a*) The motor cut-out switch MCO which may be used to isolate a defective pair of motors and which on doing so automatically modifies the control circuit to prevent acceleration beyond the series running positions.

(*b*) The wheel-slip relays which, by measurement of the back e.m.f. across the armatures of each of two series-connected motors, detect slipping by the resultant voltage out-of-balance. Slipping is then indicated to the driver by a pilot lamp in the cab.

(*c*) The current limiter, a device operated by rate of increase of current, which, in the event of a serious fault, inserts a limiting resistance into the circuit and then causes the line-breakers to open the resulting reduced current. This action reduces the load on the line-breakers under overload and short circuit conditions by a considerable amount.

The connections of the various auxiliary equipment, e.g. motor-generator set, compressors, blowers, etc., are shown on the left of the diagram. These are started by switching direct on to the line, a small buffer resistance being permanently included in the circuit

to limit current peaks on starting and due to fluctuation in the supply voltage.

The control circuits are shown in Fig. 32B and with the aid of the power contactor chart the reader should have no difficulty in tracing the sequence of operation, which commences as follows :

According to the driving position selected, the appropriate control switch (No. 1 or No. 2) is closed, the overload trip and set switch moved to " set " and then allowed to return to the " off " position to which it is self-resetting. This action energises wire 22A and current passes through the fingers 22A–22 on the controller (this verifying that the latter is in the " off " position), then through wire 22 to the overload relay reset coils resulting in any relays in the tripped position being re-instated for operation. The reverser handle is then set to the direction required and, on movement of the main control handle to notch 1, current passes from the control switch through wire P, the controller fingers and segments and wire 14 to the reverse drum whence it passes through either F or R wires to the appropriate reverser operating coil. In consequence, the reverser moves over to the desired position and then by its interlocks energises wire C. As the position relay is already closed through wire 14 from the controller, a supply is now connected to LS1, LS2 contactor coils from where it passes through the overload relay auxiliary contacts, the limiter contacts and the blower relay to earth. LS1, LS2 then close and as wires 15, 16, 18 are energised from the controller on notch 1, S1, S2, F1, F2 are also closed, with the result that current begins to flow in the main power circuit. The resulting traction motor current closes the No-current relay, NCR, and retains LS1, LS2 contactors closed through the No-current relay contacts C-C1 and " LS1 in " interlock.

(*Note* : The method of stating the type of any interlock, e.g. " LS1 in " refers to the position of the contactor or relay, etc., when the auxiliary circuit is completed.)

Two points are worthy of mention at this stage :

(*a*) The position relay PR whose function is to close on the first notch only, after which the supply passing through its contacts is by-passed by the no-current relay. In the event of a supply failure, the no-current relay drops out, opening the contactors, and this ensures that the controller must be returned to notch 1 before the power circuit can be restored.

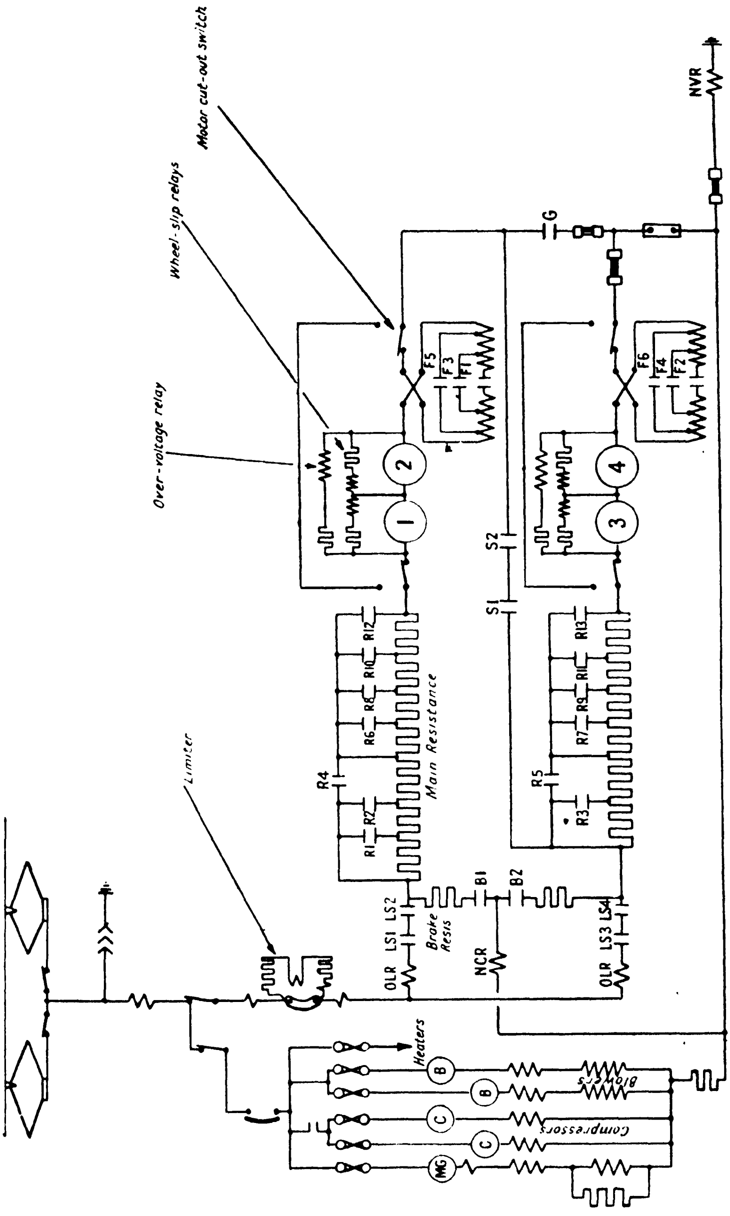


FIG. 32A. Power circuits 1500 volt d.c. four motor locomotive with rheostatic braking.

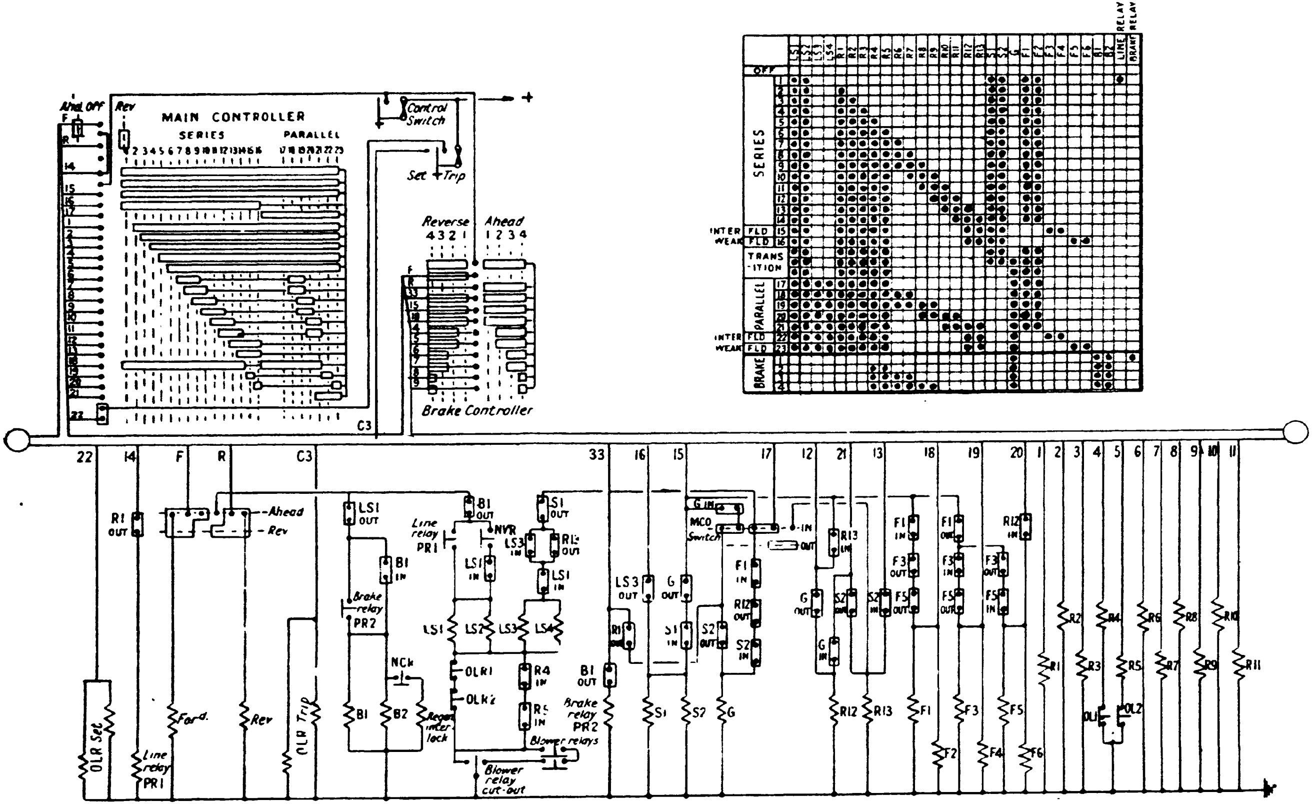


Fig. 32b. Control circuits 1500 volt d.c. four motor locomotive with rheostatic braking.

(*b*) The blower relays, which prevent the completion of the main power circuit until the traction motor blowers are in operation, this being effected by feeding the line-breaker control supply through auxiliary contacts on the blower relay.

Proceeding to notch 2 on the main control handle, wire 1 is energised and closes R1 contactor, which cuts out the first section of resistance and by means of auxiliary contacts of the " R1 out " type drops out the position relay in order to produce the effect outlined in the previous paragraph. As the control handle is moved on notch by notch, the various control wires are energised and so close the contactors in the desired sequence. Careful study will enable the reader to appreciate the various circuits, as a complete description would be of such length as to prohibit its inclusion here. The majority of the interlocks shown are preventive measures to protect the circuit from a faulty sequence of the contactors.

It will be noted that the control wires are carried to multiway coupler sockets at each end of the locomotive in order to permit the use of multiple-unit operation when required, i.e. the working of two or more locomotives coupled together under the control of one driver situated at the head-end of the leading unit.

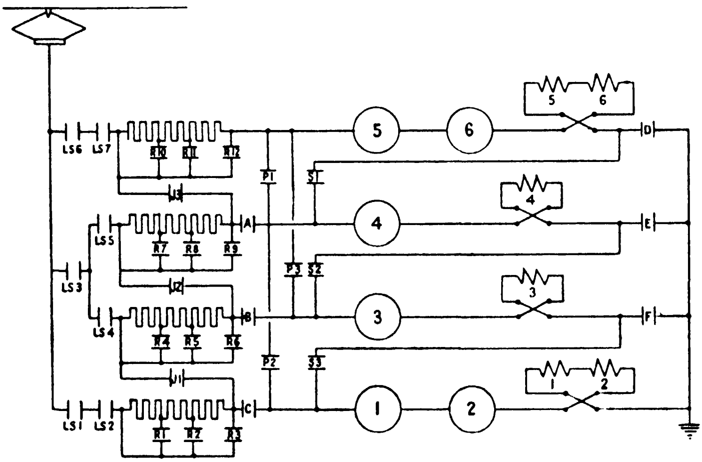
Double Series-Parallel Control. In cases where four motors are employed, each of which is wound for full line-voltage, three sequences of motor combination connection may be used for acceleration purposes, viz. 4 motors in series, 2 pairs in series-parallel, 4 motors in parallel. A control system utilising such a series of combinations is known as " double series-parallel " and may be employed with motors in the following combinations:

COMBINATIONS

1	2	3
4 in series	2 pairs in series parallel	4 in parallel
6 in series	2 circuits in parallel each with three motors in series	3 circuits in parallel each two motors in series

Other combinations may also be employed, as, for example, with eight machines each wound for half line-volts where scheme (*a*) would be employed with each pair of motors connected in permanent series and treated as one machine.

Fig. 33 shows a simplified power circuit for method (*b*) employing six motors and includes a contactor chart to enable the operation sequence to be followed. In brief, this is as follows. In the series combination power is supplied through LS1, LS2, the four resistance sections, and their links J1, J2, J3, to the six motor



		LS1	LS2	LS3	LS4	LS5	LS6	LS7	J1	J2	J3	A	B	C	D	E	F	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	S1	S2	S3	P1	P2	P3
SERIES	1	●	●						●	●	●																			●	●	●			
	F	●	●						●	●	●							●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			
	TRANS	●	●						●	●	●																			●	●	●			
		●	●	●		●			●	●	●					●														●	●	●			
		●	●	●		●			●		●					●														●		●			
SERIES-PARALLEL	1	●	●	●		●			●		●		●			●														●		●			●
	F1	●	●	●		●			●		●		●			●		●	●	●	●	●	●	●	●	●	●	●	●	●		●			●
	F2	●	●	●		●	●	●	●		●		●			●		●	●	●	●	●	●	●	●	●	●	●	●	●		●			●
	F3	●	●				●	●	●				●			●		●	●	●	●	●	●	●	●	●	●	●	●	●		●			●
	TRANS	●	●				●	●	●				●			●														●		●			
		●	●				●	●	●				●	●	●	●														●		●			
		●	●				●	●						●	●																				
PARALLEL	1	●	●	●	●		●	●		●		●		●	●		●														●		●	●	
	F1	●	●	●	●		●	●		●		●		●	●		●	●	●	●	●	●	●	●	●	●	●	●	●		●		●	●	
	F2	●	●	●	●	●	●	●		●		●		●	●		●	●	●	●	●	●	●	●	●	●	●	●	●		●		●	●	
	F3	●	●	●		●	●	●				●		●	●		●	●	●	●	●	●	●	●	●	●	●	●	●		●		●	●	

Fig. 33. Double series-parallel control.

armatures, their fields, the series links S1, S2, S3 and so to earth. Transition by the shunt method to the second combination (i.e. armatures 1, 2, 3 in series and 4, 5, 6 in series) is obtained by re-inserting the starting resistance, then closing E, LS3, LS5, then opening J2, S2 and finally closing B. When the running position has been reached with this combination and all resistance is out of circuit, contactors LS6, LS7, close and replace LS3, LS5, J3,

which then open. Transition to the third combination (i.e. three pairs of motors in series-parallel) is achieved by again re-inserting the starting resistance, then closing C, D, followed by opening J1, B, S3, E, and finally closing LS3, LS4, J2, A, S2, F. After the starting resistance has again been cut out, LS5 closes to replace LS4, J2, which then open. Special note should be taken of the equalising contactors P1, P2, P3, whose function is to counteract any out-of-balance current in the second and final combinations.

Camshaft Control. The power and control circuits of a typical electric-camshaft controlled locomotive are illustrated in Fig. 34. This locomotive is of the four-motor type with each pair of motors permanently connected in series ; it is suitable for operation on either 1500 volts or 3000 volts according to the winding of the armatures. Series-parallel control is incorporated, the power circuit being similar to that in Fig. 32, but, in this case, only three running notches are provided, one with series motor combination and two with parallel, field shunting being utilised for this purpose. All contactors except LB1, LB2, LR, are cam-operated, these three being E.P. unit-switches.

The camshaft is moved by means of a small motor operating under the control of a camshaft motor relay, whose function is, when closed, to supply current to the motor armature, and, when opened, to short-circuit the armature as a means of immediate stopping. Direction of motion of the camshaft is controlled by the auxiliary contacts of line breaker LB2 in such a way that the camshaft can only advance when LB2 is closed, and return to the " off " position when LB2 has opened. This arrangement permits the elimination of blowout arrangements on the majority of the cam-contactors by confining current rupture to the three unit-switches. Attached to the camshaft is the position regulator which, aided by the position relays, these operated from the master controller, is the means of controlling the progress of the camshaft. Note the notched segment at the lower end of this regulator, a device adopted to ensure that the camshaft does not stop between the positions corresponding to the correct accelerating and running notches. Operation is as follows :

On closing the control switch and setting the reverse handle, current is supplied through wires P and 1 to close the supply relay SR. Movement of the main control handle to notch 1 then supplies current through the " dead-man-handle " contacts to P1

finger, through the controller segments and P2 wire to the reverse cylinder, and so to the appropriate wire F or R according to the direction of motion required. The reverser, in consequence, sets itself in the requisite direction and so energises LR

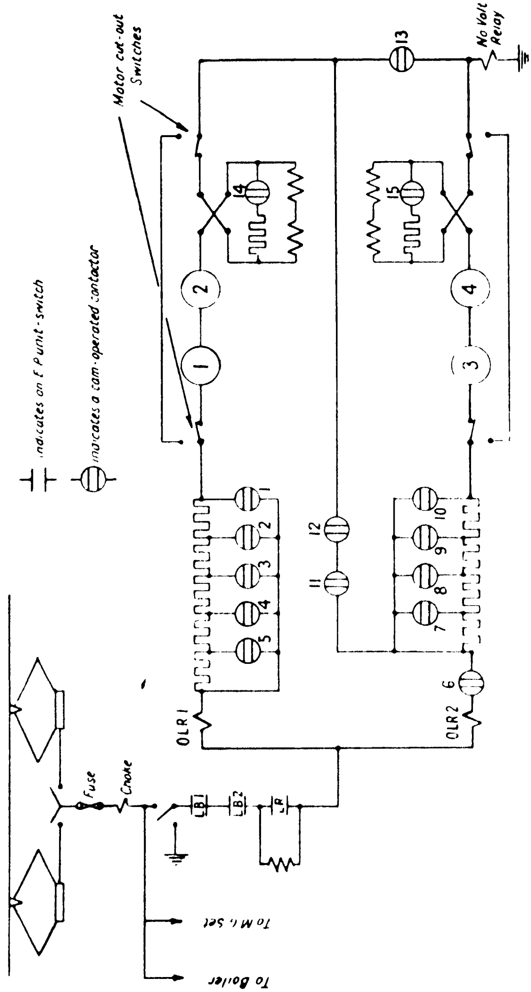


FIG. 34A. Power circuits for camshaft control.

contactor operating coil, which on closing energises the coils of LB1, LB2 contactors by means of an " LR in " interlock which makes a connection to the supply relay. As cam-contactors 11, 12, are closed in the " off " position of the camshaft, the

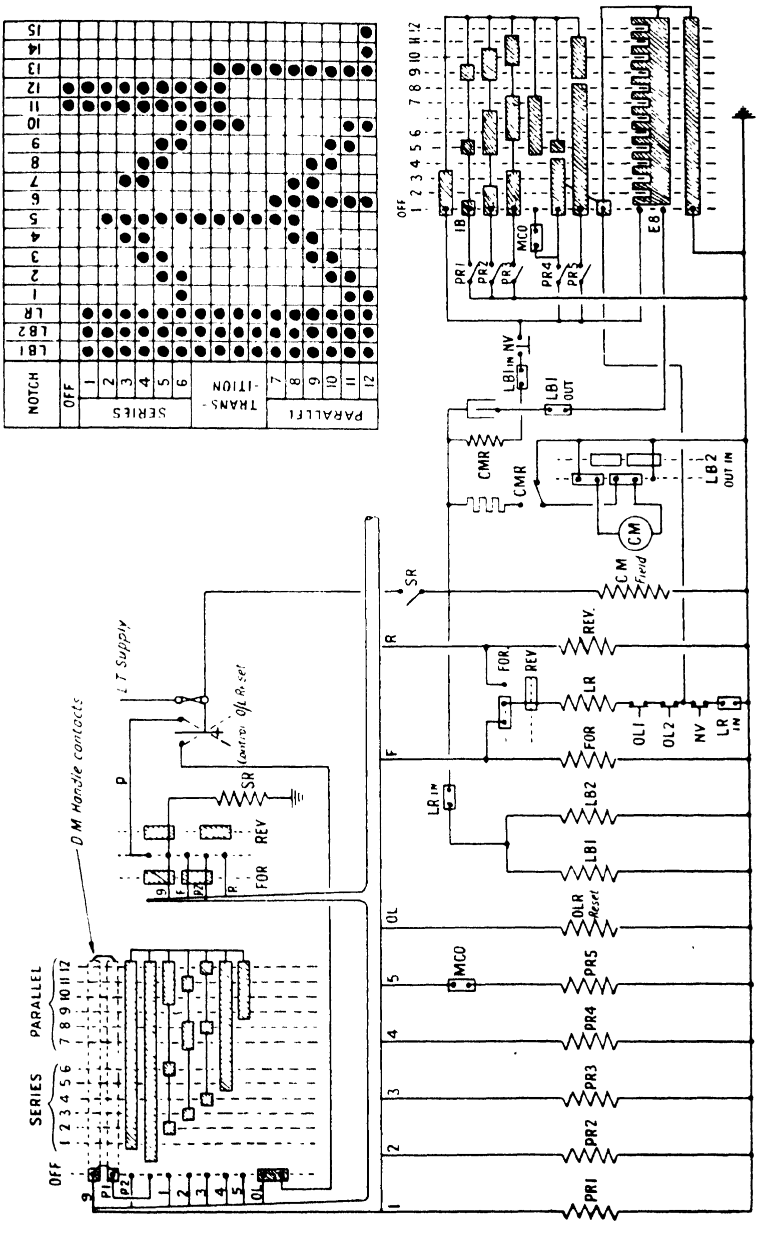


FIG. 34B. Control circuits for electric camshaft control.

closing of LR, LB1, LB2 enables current to flow in the main motor circuit and hence will cause the no-current relay to function so as to provide a retaining feed for LR contactor through the " LR in " and " NCR in " interlocks.

On moving the main control handle to notch 2, position relay PR1 is energised through wire 1 and this closes the cam-motor relay coil circuit through " LB1 in," " NCR in " interlocks, the position regulator and PR1 contacts. As the camshaft moves forward, this circuit is interrupted at the position regulator contact 1B, but the camshaft proceeds as described earlier until the notch 2 position is reached where cam-contactor 5 is closed and a portion of the main starting resistance cut out. All twelve accelerating and running notches are obtained in the same way by closing the various position relays, first separately and later, in combination.

To return the camshaft to the " off " position, the main control handle is first returned, an action which interrupts the feed to LR coil so that LR contactor drops out followed by LB1, LB2, this opening the power circuit. The auxiliary contacts of LB2 consequently reverse the camshaft-motor armature connections, the " LB1 out " interlock closes the cam-motor relay through wire E8 and the notched segment of the position regulator, so that the camshaft now returns to the " off " position again. Two points in the scheme are worthy of special mention :

(*a*) The method of current rupture which is arranged so that LR contactor always opens first, and itself trips LB1, LB2 by means of auxiliary contacts. This has the effect of inserting a resistance into the main supply before rupturing the current on the line-breakers, a feature which considerably eases the duty of the latter.

(*b*) The method of motor cut-out which shorts out a defective pair of motors and by means of two pairs of auxiliary contacts, one in the position regulator finger circuit and one in position relay PR5 operating coil lead, prevents the camshaft from travelling beyond the series position.

Electric Braking Schemes

Two forms of electric braking may be employed on an electric locomotive. These are :

(*a*) " Regenerative Braking," in which the energy from the

motors functioning as generators is fed back into the trolley-wire and is used to assist the supply to other locomotives consuming power. In consequence, this scheme is only suitable for use in a system of such size that there is always some load capable of utilising the returned power. Special types of sub-station equipment are required, but, on the whole, a considerable economy in power consumption can be effected where long and heavy gradients are involved.

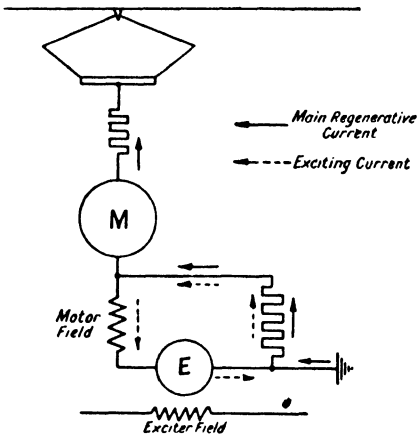
(*b*) " Rheostatic Braking," where the generated energy is dissipated in the starting resistances of the locomotive and is thereby completely wasted. This system has the advantage that it is always positive in action, as, for braking purposes, the locomotive is independent of the supply line and, further, special sub-station equipment is unnecessary. However, if long descending gradients are involved, this method obviously results in a much heavier capacity starting resistance group being required, together with an efficient resistance chamber ventilation system.

Regenerative Braking. In order that a motor may return current to the overhead line, it is necessary to raise its generated or back e.m.f. above the pressure of the supply. This is accomplished by separate excitation of the motor field from a small exciter which can be either driven by a separate motor, attached to an existing motor-generator or blower set, or driven from one of the road axles. The brake is brought into operation by connecting the motor fields to the exciter armature and then increasing the exciter field current, under the control of a rheostat operated by the brake handle, until sufficient power is being returned to the line to produce the required braking effort. In order to stabilise the re-generated current, the method of connection shown in Fig. 35 (*a*) is adopted, in which the field of the traction motor is connected to earth through the exciter armature, with a non-inductive shunting resistance in parallel. This circuit functions so that, if the line voltage falls, the increase in regenerated current produces a greater voltage drop across the resistance, with consequent reduction in the exciter field current and vice versa. The paths of regenerated and excitation currents through the circuit are indicated separately by arrow-heads.

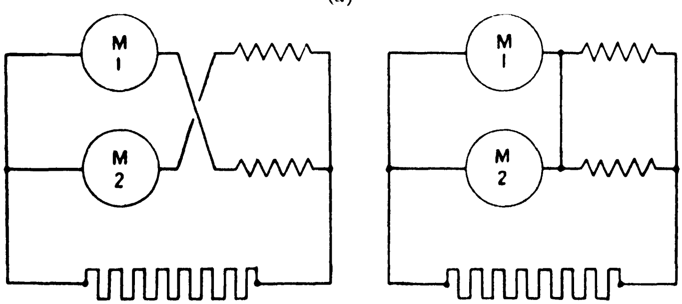
When regeneration is being employed over an undulating track, should the speed of the locomotive fall on an up-gradient to such an extent that the main motor voltage drops below that of the

supply, a motoring current is automatically taken and speed will be maintained without any change in the controller position.

Rheostatic Brake. To obtain a braking effort from a series traction motor using self-excitation it is necessary to reverse the field and armature connections relative to each other. If this is



(a)



(b)

FIG. 35. Simplified braking circuits for (a) regenerative and (b) rheostatic systems.

done and a suitable resistance is then connected across the motor terminals, the machine will build up as a generator and cause a current to flow in the circuit, thereby dissipating energy in the resistance and exerting a retarding effort on the motor armature. Again it is necessary to have some form of stabilising connection when two motors are in use in order to equalise the braking effort from each motor. Two methods of connection are available (Fig. 35 (b)) and various elaborations of these schemes are employed

according to the number of motors concerned. Control of the braking effort is obtained by variation of the loading resistance using the unit-switches normally employed for starting purposes. The power connections necessary to provide for an electric brake of the rheostatic type are shown in Fig. 32A, the control of such a system being accomplished using a controller of the drum type which may be incorporated in the master controller, if desired. (*Note* : Fig. 32B includes the control connections for such a brake using a separate brake controller.)

Alternating Current Motor Control

As described in Chapter Two, single-phase alternating current traction motors are only satisfactory in operation on comparatively low voltages compared with D.C. machines, but, notwithstanding this fact, normal practice is to operate such motors connected either all in parallel or as a number of parallel groupings of two machines in series. One great difference between direct and alternating current is the ease with which the latter by using a transformer may have its pressure changed. In consequence, most A.C. locomotives are supplied at voltages ranging from 10,000 to 20,000 at frequencies of either $16\frac{2}{3}$ or 25 cycles per second. Current is collected by the pantograph at this pressure and passed through a circuit breaker to the primary winding of a transformer where the pressure is changed to one suitable for supplying the motors. Before proceeding further, a brief outline of the basic principles of a transformer will be of advantage.

Transformers. The transformer consists essentially of two entirely independent electrical circuits linked together by means of a common magnetic circuit arranged so that energy at high voltage may be transformed into energy at low voltage and vice-versa. The winding of a transformer which is connected to the incoming supply is known as the " primary ", whilst that to which the load is connected is known as the " secondary ", both these windings consisting of coils mounted on a closed iron circuit normally made of silicon steel or other similar steel having low magnetic losses. When alternating current at a certain voltage is applied to the primary winding, it produces an alternating flux in the iron core of the transformer, which then induces an alternating e.m.f. in the secondary winding, the ratio between the applied and induced voltages being approximately the same as the ratio

between the number of turns in the primary and secondary windings, the slight discrepancy being due to resistance and magnetic losses, efficiency and mechanical construction. Similarly, the ratios of the currents in the two windings are, approximately, in the inverse ratio to the turns of the respective windings so that when no load current is flowing in the secondary it follows that the primary current will be small.

The auto-transformer is one in which the secondary winding is common with a portion of the primary, with the result that a small proportion of the load is supplied directly with current from the primary and the remainder by induced current from the secondary.

Both these types of transformer are employed in railway applications and examples of their use are quoted later. A typical transformer is shown in Fig. 36 both with the enclosing tank removed and in position.

In order to enable the transformer to dissipate the heat generated in its windings and core due to resistance and magnetic losses, some form of cooling system is required. Several methods are available, those most common in electric locomotive practice being :

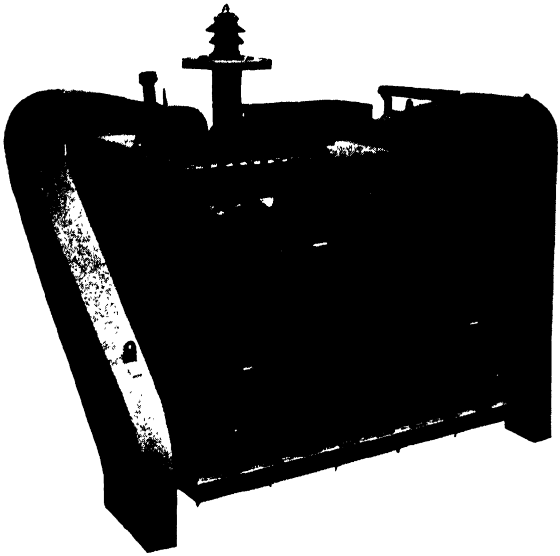
(*a*) The air-blast transformer in which cooling is carried out by blowing large volumes of air over the transformer windings and core.

(*b*) The oil-immersed forced-air-cooled type in which the windings are immersed in oil, which is cooled by passing through corrugations or tubes mounted externally on the sides of the tank. Oil circulation may be natural or by pump, surface cooling of the tubes either by natural draught or air-blast.

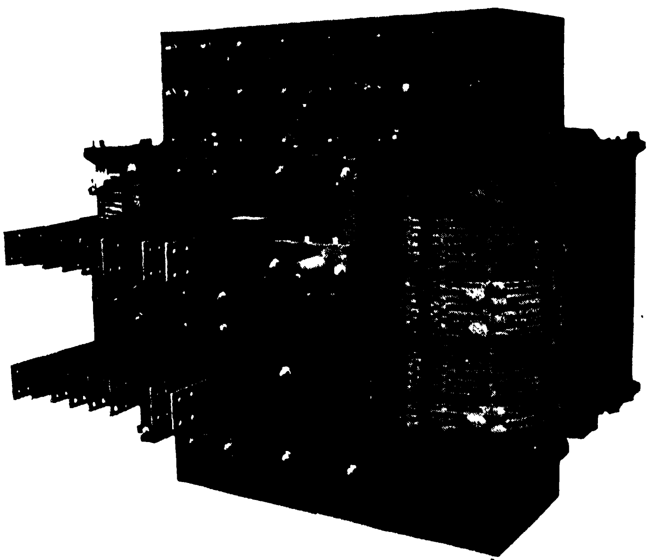
(*c*) The oil-immersed separately-cooled transformer operates in conjunction with an external cooler to which the oil is circulated by pumps. The external cooler frequently consists of a series of tubes mounted beneath the main frames, or attached to the sides and roof of the locomotive casing.

Application of the Transformer to Locomotive Control

By arranging a series of tappings on the secondary winding of a transformer, it is possible to provide a range of voltages varying from zero to the maximum output of the transformer, and for motive power purposes, use is made of such a series of tappings to accelerate the traction motors, starting on the lowest tap and



(i)



(ii)

FIG. 36. Typical locomotive transformer complete and with tank removed.

increasing the applied voltage progressively until the desired running speed is attained. In contrast with D.C. systems, such a method of control is ideal in that each tapping point is a running position on which the locomotive can operate continuously if necessary.

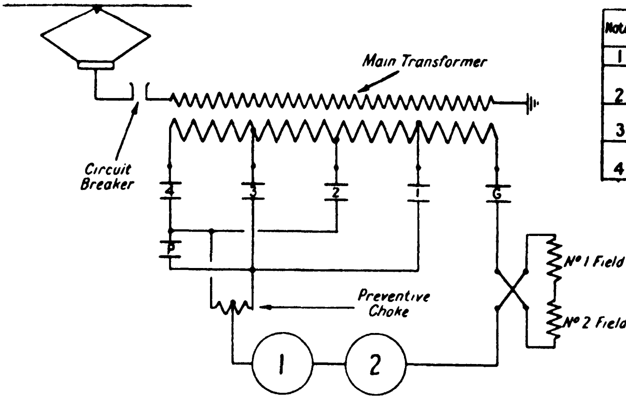
In general, the various methods of control developed for single phase A.C. locomotives consist of some means whereby the motors may be connected to the various tappings in sequence, and each incorporates a method of transferring the load from one tapping to the next without interruption of the tractive effort together with a variety of protective devices for fault detection, etc. For this purpose two systems may be used :

(*a*) The sliding contact tap-changer where leads from the transformer tappings are brought in sequence to a series of contacts, along which travels a moving brush arm traversed by a lead-screw or chain.

(*b*) The contactor group, where the motor is connected to the transformer tappings by the closing in sequence of a series of contactors, similar in construction to the unit-switch described earlier in this chapter, but incorporating laminated yokes, cores, etc.

Whichever method of tap-changing is employed, it is necessary to connect two adjacent tappings of the transformer to the motor terminals simultaneously at the instant of change-over, due to the desirability of maintaining a continuous output of power. In consequence of this connection, the portion of the transformer winding between the two tappings concerned is short-circuited. As such a connection is most undesirable due to the heavy circulating currents which would ensue, steps are taken to eliminate such difficulties by the incorporation of preventive chokes or coils into the circuit. To illustrate this method, a simple circuit using such a choke appears in Fig. 37A.

The preventive coil or choke consists of a low resistance, or, preferably, an inductance, which is incorporated into the circuit as shown above. From reference to the contactor chart it will be seen that during tap-changing the choke is inserted between the two adjacent taps concerned, but during running is short-circuited to reduce its effect and losses. This connection is obtained by closing the contactor P, and, where an inductance is used, the effective impedance is very small, as current flows in opposite directions in the two halves of the coil.



Contactors

Notch	G	1	2	3	4	P
1	●	●				●
	●	●	●			
2	●		●			●
	●		●	●		
3	●			●		●
	●			●	●	
4	●				●	●

Fig. 37A. Use of preventive choke in conjunction with tap-changing by contactors.

A similar arrangement may be used in conjunction with a double sliding contact tap-changer and Fig. 37B shows a simple circuit of this type, but incorporating an auto-transformer in place of the ordinary transformer in the previous figure. The

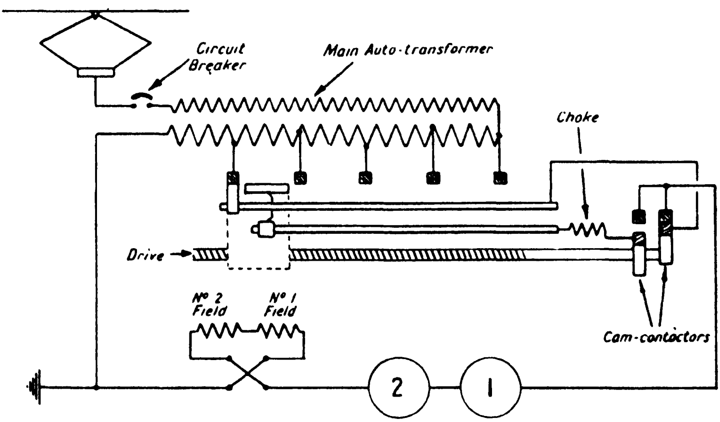


Fig. 37B. Use of preventive coil in conjunction with sliding contact tap-changer.

two small contactors are cam-operated and are so timed that all " making and breaking " of current is carried out on them, a feature which protects the sliding contacts, whose duty is confined to the carrying of current only.

The maximum number of tappings which can be conveniently

incorporated into the secondary winding of the main transformer is in many cases insufficient to provide the requisite number of motor voltages for locomotive speed control purposes and certain methods have been devised to overcome this difficulty. In brief, they are as follow :

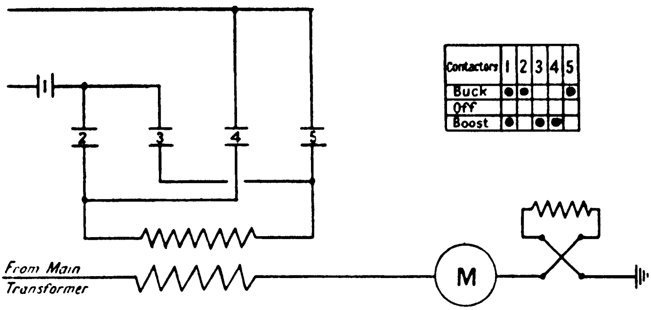
(*a*) A separately-excited auxiliary transformer is introduced into the circuit with its secondary winding in series with the output from the tap-selector equipment. Excitation of this small transformer is controlled by a series of small contactors and is reversible so that its secondary e.m.f. may either (1) " boost " or raise the main transformer voltage ; (2) make no contribution at all ; (3) " buck " or reduce the main voltage. This arrangement has the effect of producing three operating positions corresponding to each tapping on the main transformer. When operated in conjunction with a sliding contact tap-changer, the small contactors will be cam-operated ; otherwise, electrical interlocking would be employed (Fig. 38(*a*)).

(*b*) A similar method to that outlined above has been developed and installed to a considerable extent on the German State Railways. This uses a separately-excited winding on the main preventive choke to induce a " bucking " or " boosting " e.m.f. therein, as required.

(*c*) Where contactor tap-changing is employed, the secondary currents are frequently of too large a value to be carried by a single contactor and, in consequence, the load is divided between three or four such units. By introducing additional preventive coils into a circuit of this type, extra running points can be obtained by utilising various combinations of contactors. Fig. 38(*b*) shows a simplified scheme where twelve contactors are employed to give fourteen operating positions from six transformer tappings. Fig. 39 shows a complete loco circuit where groups of three contactors are used.

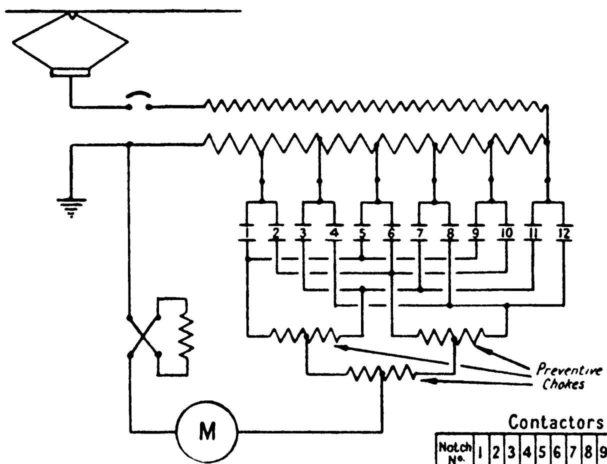
Typical Locomotive Control Scheme. Fig. 39 shows the power and control schemes and contactor chart for a two-motor locomotive, simplified by the elimination of all auxiliary equipment circuits. Eighteen contactors are employed with six voltage tappings on the main transformer and two preventive chokes, and are arranged to give 16 running and 1 inching notch by contactor grouping. The main tapping voltages are 168, 264, 384, 508, 672, 840. Resultant voltage outputs to the two traction motors

which are wound for 390 volts and connected in series are 168, 200, 232, 264, 304, 344, 384, 432, 480, 528, 576, 624, 672, 727, 784, 840, these being obtained by closing three adjacent contactors



Contactors	1	2	3	4	5
Buck	●	●			●
Off					
Boost	●		●	●	

(a)



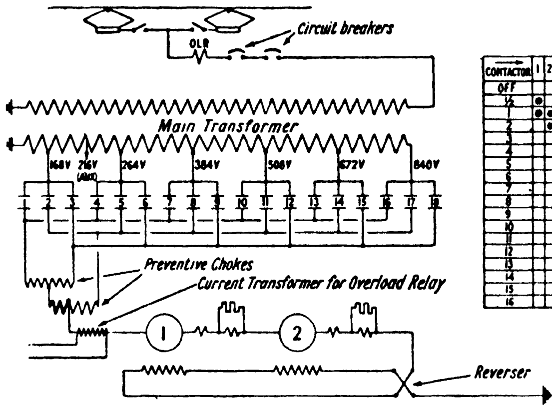
Contactors

Notch No.	1	2	3	4	5	6	7	8	9	10	11	12
1	●											
2	●	●										
3	●	●	●									
4	●	●	●	●								
5		●	●	●	●							
6			●	●	●	●						
7				●	●	●	●					
8					●	●	●	●				
9						●	●	●	●			
10							●	●	●	●		
11								●	●	●	●	
12									●	●	●	●
13										●	●	●
14											●	●

(b)

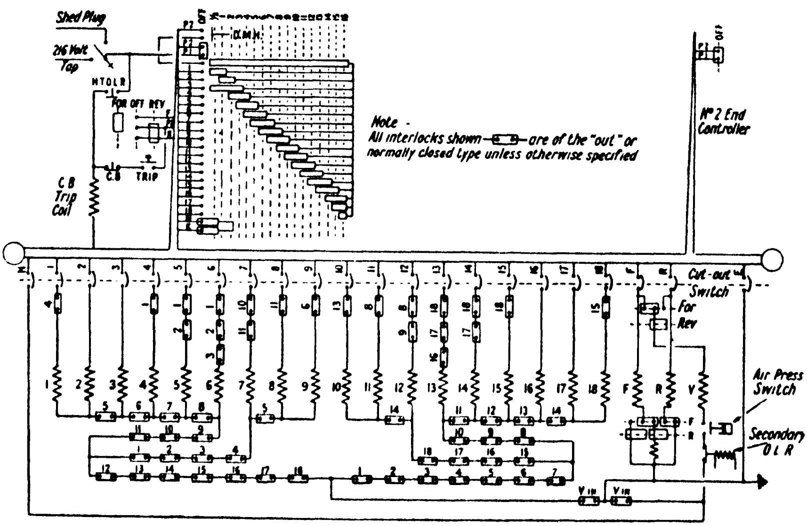
FIG. 38. Methods of obtaining additional operating positions from a given number of contacts.

simultaneously throughout the accelerating sequence. Note the large number of interlocks which ensure that only three adjacent contactors can be closed at the same time and hence that no two



CONTACTOR →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
OFF																		
½	●		●															
1	●	●	●															
2		●	●	●														
3			●	●	●													
4				●	●	●												
5					●	●	●											
6						●	●	●										
7							●	●	●									
8								●	●	●								
9									●	●	●							
10										●	●	●						
11											●	●	●					
12												●	●	●				
13													●	●	●			
14														●	●	●		
15															●	●	●	
16																●	●	●

(i)



(ii)

FIG. 39. Power and control circuits of two-motor A.C. locomotive with contactor tap-changing system.

tappings on the transformer can be short-circuited. The following points are worthy of mention :

(*a*) The electro-magnetic reverser is arranged to operate on full

control voltage and then to insert an economy resistance into the circuit by means of its auxiliary contacts, in order to reduce heating in the operating coils during the retaining period when the locomotive is in motion.

(*b*) The blower contactor, which controls the traction motor and transformer cooler fan motors, is arranged to close when the reverser has taken up its correct position, and carries auxiliary contacts to prevent operation of the power contactors until the blowers are running. This contactor can only be closed in the " off " position and on notch 1 of the controller, and, once closed, retains itself by means of interlocks until the reverse handle is returned to the " off " position.

(*c*) The main circuit breaker can be tripped by hand, by pressing a button in the driving cab, or by an excessive line current causing the overload relay to function.

(*d*) A secondary circuit overload relay OLR2 is arranged to trip out the blower contactor and hence the power contactors should an overload occur in the traction motor circuit. It is operated by an instrument current transformer in series with the main secondary current.

(*e*) To guard against damage to the equipment should both controllers be brought into operation at the same time by the incorrect observance of the regulation permitting only one reverse key per locomotive, an electrical interlock P1–P2 is provided so that, unless one controller is in the " off " position, no control supply is available.

The locomotive is arranged for multiple-unit operation and, in the event of any failure of the electrical equipment when operating in such manner, all contactor and reverser circuits can be isolated by the operation of the multiple-way cut-out switch.

Control Apparatus. Typical control equipment is shown in Fig. 40, comprising tap-changing mechanisms. Certain manufacturing concerns prefer to use mechanical means for operation of the tap-selecting equipment, as this, of course, eliminates the necessity for a complicated control circuit involving a large number of interlocks. This applies in particular on small locomotives where the controller handle is arranged to operate a sliding contact tap-changer or group of small cam-operated contactors by direct means. An interesting mechanical drive is that developed by the Société Anonyme des Ateliers de Sécheron, in which the operating

valves of a bank of pneumatic contactors are controlled by a series of cams mounted on a camshaft, this camshaft being driven from the main controller handle through reduction gearing. The complete unit, known as a mechano-pneumatic contactor group, is

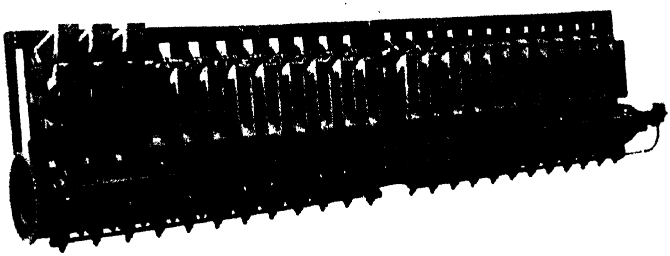


FIG. 40A. Mechano-pneumatic contactor group.

illustrated in Fig. 40A and it will be noted that 24 contactors are involved, the control of which by electrical means would involve a terrific number of interlocks for protective purposes.

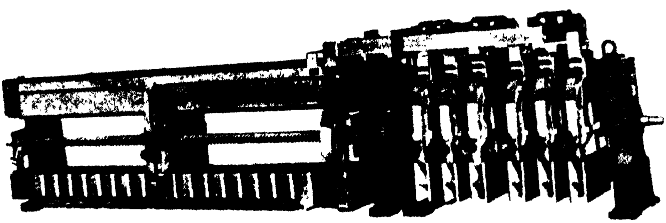


FIG. 40B. Sliding-contact tap-changer.

High-Tension Control. The most recent development in single-phase A.C. locomotive control is that where the output to the traction motors from the secondary winding of the transformer is varied by regulation of the primary circuit, a method developed in Switzerland. As a result, only relatively small currents are involved in the tap-changer, this permitting considerable economy in weight and space and simplification of the low-tension control gear, which now comprises the reversers and one

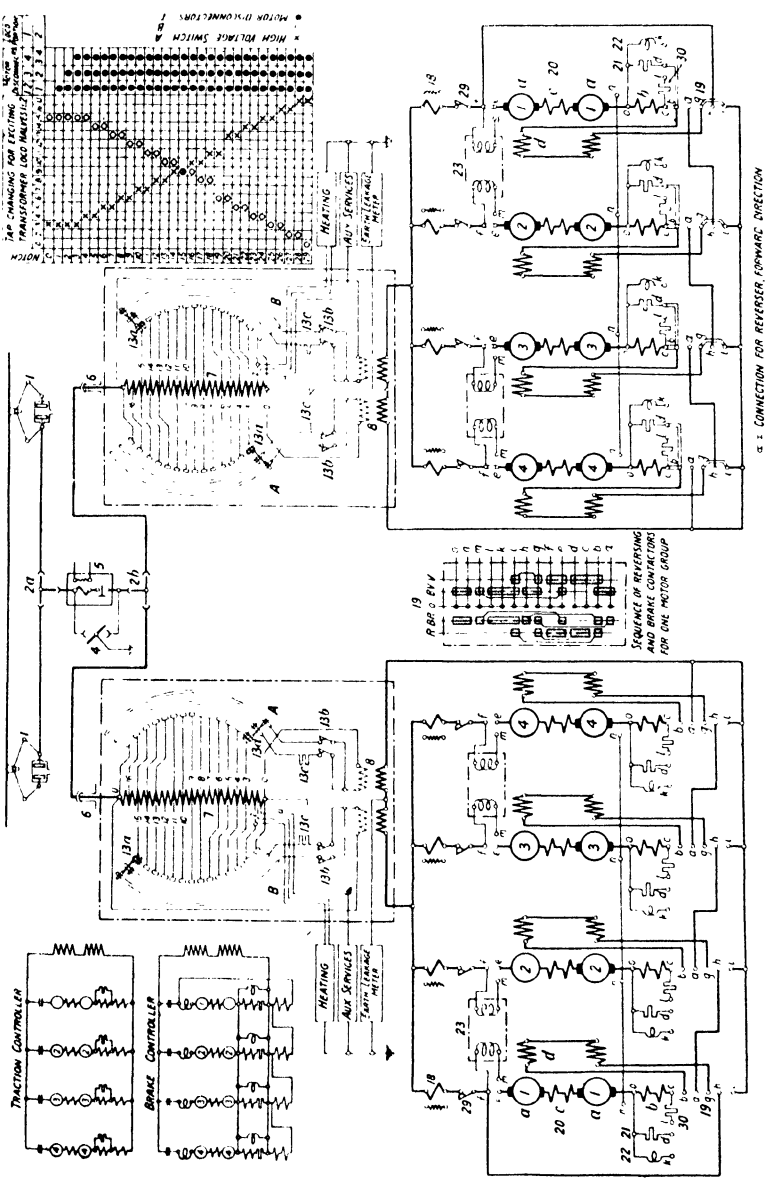


FIG. 41. Power circuit—12,000 h.p. locomotive with high-tension control.

E.P. unit switch for each traction motor group. A 12,000 h.p. twin-unit locomotive and a number of 6000 h.p. units employing this method of control have been placed in service during the last few years on the Swiss Federal Railways; these are dealt with in Chapter Six. The power-circuit of the twin-unit machine is shown in Fig. 41.

Two views of the main transformer appear in Fig. 42. Each transformer consists of one regulating and two secondary transformers situated in a common oil tank, together with the high-tension tap-changer in an adjacent tank, the whole being designed so as to incorporate all high-tension connections inside the tanks. Two tap-changers, operating alternately, supply the secondary transformers with voltages tapped from the regulating transformer, this arrangement providing 29 running steps from half that number of tappings on the regulating transformer. The low-tension windings of the two secondary transformers are connected in series and supply the eight traction motors, these being arranged as four parallel circuits of two machines in series. Cooling of the transformers is carried out by forced oil-circulation through fan-cooled radiators, a novel but simple design of pump being employed in which the necessity for glands is eliminated, by allowing both motor and pump interior to be filled with the circulating oil.

The tap-changers (Fig. 42) are plate type with rotary tapping arms, fitted with transfer resistances and contactors to ensure a smooth change-over from one tap to the next and to prevent rupturing of current on the tapping arms and contacts. These contactors are cam-operated, and each complete tap-changer assembly is driven by an independent motor, remotely controlled by a master controller in the driving cab. Should either of the two main controller handles be moved to a certain notch, the tap-changing motors come into operation and rotate the tap-selecting equipments to the corresponding position. The control system for this purpose is somewhat similar to that for a D.C. all-electric camshaft and is so designed that the tap-changers in each half of the locomotive reach identical steps simultaneously, thereby evenly distributing the load between the two motor-groups. In the event of failure of this electrical drive to the tap-changer, manual operation is possible from the controller in the section concerned. The driving mechanism is illustrated in Fig. 43.

Regenerative braking is incorporated in the system and for this

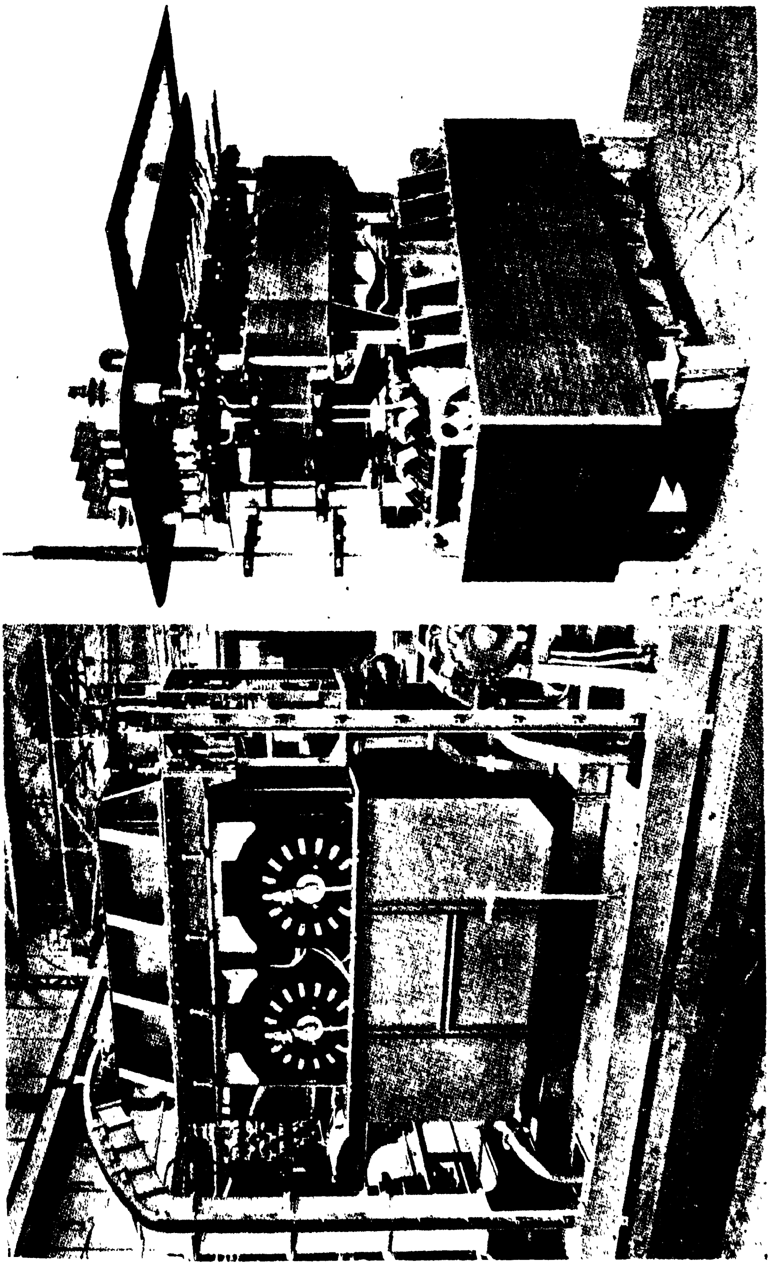


FIG. 42. Two views of main transformer for high-tension control.

purpose the eight traction motor fields are re-connected in series with excitation supplied from the secondary transformer. The armature grouping remains as for motoring, but a number of induc-

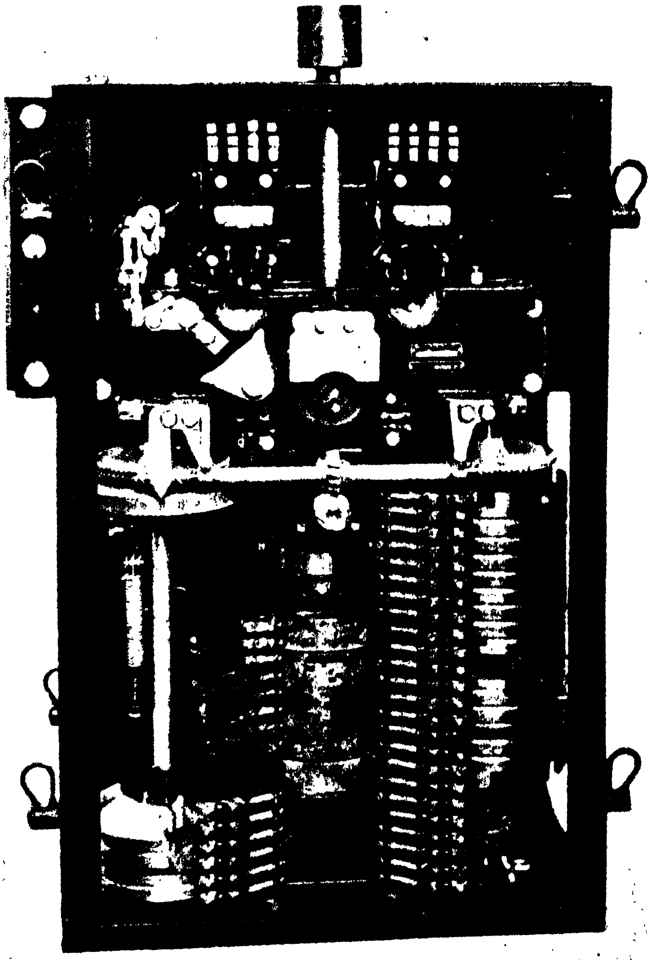


FIG. 43. Tap-changer driving mechanism.

tion coils and chokes are introduced into the circuit. Change-over from power to brake is accomplished by movement of the power-brake control handle to the brake position, after which the main control handle may then be "notched-up" until the

requisite braking force is obtained. Four electro-magnetic five-position drum-type switches, one for each pair of motors, are employed for making the circuit combinations necessary both for reversal and power-brake changeover. These are arranged so that they can only function when the unit-switches are open and hence do not rupture any current. Auxiliary diagrams to Fig. 41 show the connection combinations and drum development of one of these selector units, together with the simplified circuits obtained in the power and brake positions.

Three-Phase Motor Control. The three-phase induction motor is inherently a constant speed machine within limits and due to this characteristic the majority of three-phase locomotives have only two or three running speeds. These are approximately constant regardless of the gradient and load and, in consequence, the motors have to be designed and rated to allow for such conditions.

An induction motor is started from rest by the connection of its stator windings to the supply with a resistance network connected to the rotor. To accelerate the machine, this resistance is progressively reduced until the running position is reached when the rotor-connections are short-circuited. Two types of resistance may be employed, a star or delta-connected wire-wound unit immersed in oil, or a liquid rheostat where the rotor connections are taken to vanes which may be immersed to a varying depth in a liquid conductor such as brine, etc.

Where two motors are installed, as on the majority of the Italian State Railway three-phase locomotives, cascade-parallel starting connections are often employed, in which two motor combinations are arranged so as to provide two running speeds. These are :

(*a*) The stator of No. 1 motor is connected to the supply. Its rotor is then connected to the stator of No. 2 motor, and the rotor of the latter machine connected to the starting resistance, this being at its maximum value. The motors are then accelerated by reducing this resistance in stages until the rotor connections of No. 2 are short-circuited at the first or lower running speed.

(*b*) The motors are then re-connected with the two stators in parallel supplied from the line and each rotor connected to its own starting resistance. Acceleration is then carried out as for a single motor until the second or higher running speed is attained when both rotors are short-circuited.

In order to provide more than one speed where only one motor is involved, a special system of winding may be employed in connection with a number of contactors, so that by variation of the winding connections the number of poles induced in the magnetic circuit of the machine may be changed with consequent

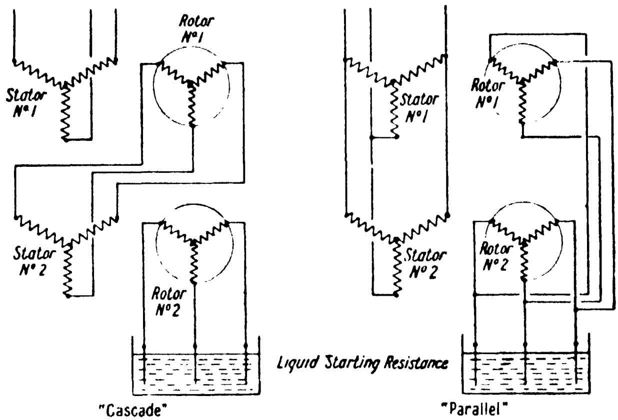


FIG. 44. Cascade-parallel starting connections for two 3-phase motors.

change in speed. A motor of this type is described in connection with the convertor locomotive of the Hungarian State Railways on page 160.

Other Systems. Several special methods of control have been developed for particular cases of convertor type locomotives, however, for simplicity these systems are described in Chapter Seven in connection with the locomotives in which they are installed.

CHAPTER FOUR

AUXILIARIES AND BRAKE EQUIPMENT

Current Collecting Apparatus

WITH a power unit of this description, which obtains its supply from a separate source, some method has to be devised to collect the electrical energy necessary without interference with movement or operation. Two systems of collection are employed, and choice between them is mainly governed by the operating voltage and type of current supply. On direct current systems, where the operating voltage is below 750, an insulated conductor rail is used, mounted adjacent to the running rails, current being collected from it by one or more collector shoes which slide thereon. To allow for cooling and continuation of supply at crossings, junctions, etc., the position of this conductor rail is alternated from one side of the running rail to the other. On certain parts of the New York Central System this rail is mounted centrally over the track for convenience of operation in tunnels and freight yards.

On all alternating current and on direct current systems with a pressure above 750 volts, power is supplied through specially supported overhead trolley wires and current is collected therefrom by one or more pantographs, a collecting device described later. This system removes the danger to track maintenance staff and, in the case of A.C., makes possible the employment of high trolley wire pressures, such as 11,000 volts in the U.S.A., 15,000 volts in Switzerland and 20,000 volts in parts of Germany.

Collector Shoes. Collector shoes may be one of three types according to the mounting of the conductor rails. These are :

(*a*) " Over running " where the shoe itself is carried on links supported in a frame attached to the shoe beam. The shoe slides on top of the conductor rail which is open at the top and may be protected at the sides if necessary (Fig. 45).

(*b*) " Side contact " where the shoe is pressed against the rail by means of a spring, the rail being mounted horizontally and protected above and on the outside.

(*c*) " Under-running," the rail being slung from special carrying arms and protected down the outside, over the top and on a

portion of the inside. The shoe is hinged on its carrier and held against the under-surface of the rail by a torsion spring.

The supporting frame is carried on hard wooden beams mounted outside the locomotive frame on rigid-framed types or on the bogies with double-bogie locos. Up to four shoes may be fitted at each side, and each feeds through a separate fuse to the main equipment of the locomotive.

FIG. 45. Over running collector shoe.

Current return is usually made through the running rails but on some systems is made through an insulated return rail mounted centrally between the running rails.

Pantograph and Roof-Gear. Collection from overhead wires by means of the pantograph is to-day standard for all electric locomotives. On all larger machines two such collecting devices are fitted and either one or both may be utilised when the locomotive is in service.

The pantograph consists of two collapsible pentagonal frames, mounted side by side in two parallel vertical planes on a common base and spaced some three to five feet apart by cross-braces. The upper members come together at the apex of the framework and there support the current-collecting skate or pan, this latter being mounted on small aluminium castings which break away if any obstruction is encountered. Certain manufacturers mount two such pans side by side if the current to be collected is more than one can satisfactorily carry—others use two pantographs together. Actual collection is carried out by renewable copper strips attached to the upper surface of these collecting skates.

The outer ends of these upper members are pin-jointed to the lower members, which are mounted on two rocker shafts supported in bearings one at each end of the base frame. These two rocker shafts are linked together and their rotation raises and lowers the pantograph.

The pantograph is balanced and adjusted by means of a system

of springs acting with cams on the rocker shaft so that when in operation the contact pressure on the trolley wire does not vary more than 25% over the whole range of operating height, the value of which may vary from one to eight feet above the base frame. Further, when the trolley wire height increases rapidly, such as when leaving a tunnel or after a low overbridge, the frame is capable of accelerating upwards at a rate sufficient to avoid any possibility of the collecting skate breaking contact with the wire.

Two methods of movement are employed, viz. the pantograph may be raised by compressed air and lowered by gravity and springs, or depressed by compressed air and raised by its springs. In the first case, the piston of the air-operating equipment is connected through springs to the rocker shafts to allow the latter freedom of movement as the trolley wire height varies. Compressed air for raising may be obtained from storage reservoirs, from a small battery driven compressor or from a hand pump operated by the driver. In the second case, compressed air from the locomotives' main supply is used to depress the framework, which is then locked down until required. A third method employed with light shunting locomotives is a variation of the latter case, the difference being that the pantograph is lowered by pulling an insulated cable attached to the apex of the frame and wound around a drum in the driving cab.

The base of the pantograph is carried on insulators mounted on the locomotive roof as the whole frame is at trolley wire potential. After collection, current passes through an isolating switch and, on direct current locomotives, through an air-cored choke coil and a fuse to the main line-breakers of the control system. A lightning arrestor of the electrolytic or condenser type is connected from the trolley wire end of the choke coil to earth, in order to protect the equipment of the locomotive against damage due to voltage surges.

On alternating current locomotives, the main transformer has a sufficient reactive effect to make the carrying of lightning arrestor gear unnecessary.

Fig. 46 shows a typical modern light-weight pantograph, and further examples of the many varieties of pantograph, etc., can be seen in the chapters dealing with the completed locomotives themselves.

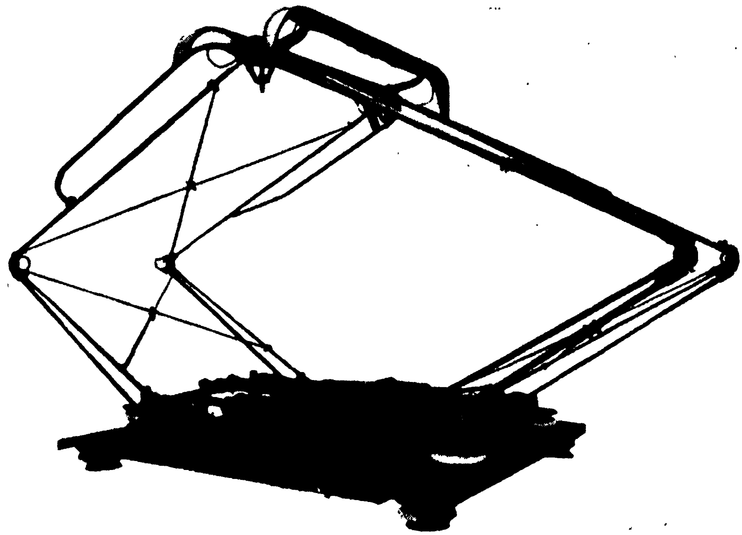


FIG. 46. Pantograph.

Auxiliary Supplies and Motor Generator Sets

On direct current locomotives, auxiliary supplies for lighting control, motor excitation with regenerative braking systems, battery charging and other purposes are obtained from one or more motor-generator sets carried inside the locomotive. Control voltages range between 32 and 150 and this is normally supplied by a shunt generator working in parallel with a battery, the latter acting as a voltage stabiliser and reserve of power.

Two types of mechanical construction are employed; the separate motor and generator type with the two machines bolted to a common bedplate and their armature shafts connected by couplings; and, secondly, the unit-constructed type in which both machines are carried in the same frame, the armatures being mounted on a common shaft, a method which is becoming more popular every year.

The driving motor is normally a shunt machine with a light series field winding to facilitate direct switching on to the main supply using a series-connected buffer resistance to limit the current rush, this resistance absorbing about 3 to 5% of the

applied voltage when the machine is running on its rated load. Also in series with the motor circuit is a series field winding on the generator main poles, which assists in maintaining the output voltage steady and also ensures that the generator builds up to the correct polarity when starting.

The generator itself is a self-excited shunt machine, with which a voltage regulator is employed to control the excitation so as to maintain a constant output voltage at all loads and during speed variation due to line volt fluctuations.

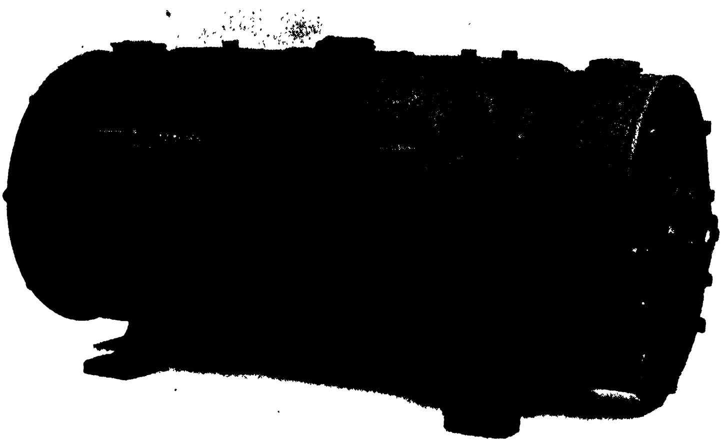


FIG. 47. Motor-generator Set.

Various other methods are employed in order to obtain stability of output voltage with variations of up to 30% or more in the line voltage. These include schemes involving cross-excitation between motor and generator and the obtaining of a constant speed M.G. set by using a light series-excited driving motor with a shunt field winding fed separately by a special exciter mounted on an extension of the armature shafts. Suitable adjustment of the field currents involved will, with this type of connection, give a voltage variation of only 2 to 3% over the full range of supply fluctuation.

Such machines are normally of the self-ventilated type and are frequently used to drive a traction motor blower fan in addition to the auxiliary load.

On alternating current locomotives, auxiliaries may be supplied from either special tappings on the secondary of the main transformer, or from a motor generator set supplying direct current and operating in parallel with a battery. In certain circumstances, both systems may be employed if required.

In Europe, the control supply is mainly alternating current at 100–250 volts, but in the U.S.A. 32 and 64 volt direct current appears to be the most popular, the small generator necessary being attached to one of the main blower sets and controlled by a voltage regulator.

Storage Batteries. Most locomotives have some type of storage battery fitted in order that the control supply, lighting, etc., is available when the motor generator set is not in operation for any reason. Two types of cell are employed, the lead acid cell and the nickel-cadmium alkaline cell. Both these types have advantages and disadvantages with respect to each other and at the present time each appears to be equally favoured by locomotive engineers, choice being influenced by initial cost, rating required and the climatic conditions in which the locomotive will operate. Readers are referred to the Appendix for comparative details as to size and ratings of accumulators employed.

As the nickel-cadmium alkaline cell is unfamiliar in general application, a brief description will be of interest at this juncture.

From the typical section shown in Fig. 48, it will be seen that this cell consists of plates built up with pockets of finely perforated steel, totally enclosing the active material, this being nickel hydroxide in the positive plate, and a mixture of cadmium and iron in the negative plate. The electrolyte is a solution of potassium hydrate and has no action on the plates themselves. The whole assembly is enclosed in a plated steel container making one cell, these cells being then mounted in hard wood insulating crates for protection and ease of handling. Note that the average voltage of nickel-cadmium accumulator cells is 1·2 volts at normal discharge, and, consequently, a larger number of cells of this type are necessary for a given voltage than with accumulators of the lead acid type.

Blowers. The use of separately ventilated traction motors with large volumes of air being forced through the motors by externally driven fans is now extensive among locomotive designers. Most fans are of the centrifugal type, air being drawn

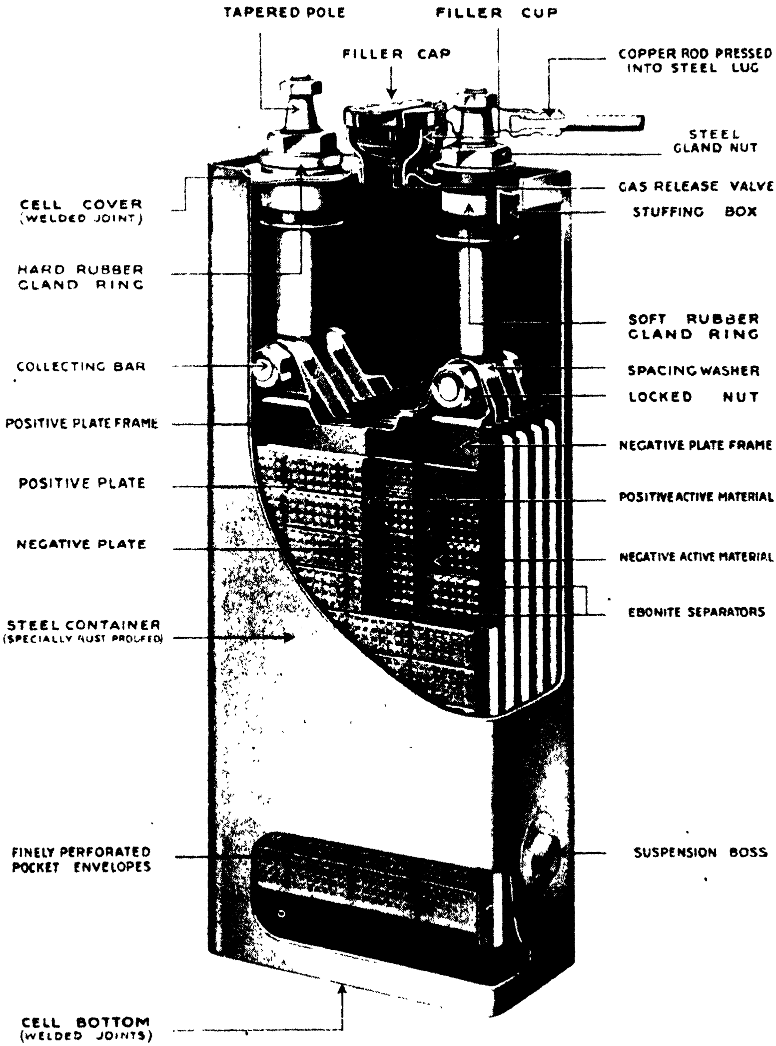


FIG. 48. Nife nickel-cadmium cell in section.

sideways into the fan at the centre and expelled tangentially at one point in the protecting cowl into rectangular steel ducting through which it is conveyed to the various motors concerned, being divided up *en route* as required. Some locomotives have only one blower ; others have two or more, but in all cases careful designing of the ducting is necessary to ensure approximately equal volumes of air being supplied to each traction motor.

As mentioned earlier, the blower fans are frequently combined with the motor-generator set, the motor of this machine being sufficiently increased in size to provide the additional torque required. Alternatively, a separate motor drive is employed, the fan being overhung at one end of a small series motor, the end plate of which carries the fan cowling. The fan itself consists of a series of blades mounted radially on a circular plate driving member and supported at their outer ends by a ring. Both fan housing and ducting are constructed of pressed sheet steel riveted or welded together.

Train Heating. The heating of electrically-hauled trains may be carried out in two different manners : by steam from a boiler installed on the locomotive, or by electrical means utilising a supply line running throughout the train and fed from the locomotive. Choice of system is governed by the extent of the electrification in that where trains are likely to be hauled by steam locomotives on certain portions of their run, steam heating must be employed or a dual heating system installed.

In Switzerland and Sweden electrical heating is employed, using a supply voltage of 800 to 1000 volts 16⅔ cycles alternating current, obtained from a separate tapping on the secondary of the main locomotive transformer, current being passed along the train by a system of special plugs, sockets and flexible jumpers. On direct current systems where electric heating is installed, several heaters are connected in a series circuit which is supplied direct from the overhead line, a system which is not feasible on alternating current systems due to the high trolley-wire voltages involved.

Most other countries, due to their electrification schemes being less extensive, employ steam heating supplied from a small boiler carried on the locomotive frames. This boiler may be oil-fired or electrically heated, but is generally arranged for automatic control, power input being governed by pressure switches or valves, and feed water supply controlled by a water switch in the

feed water pump motor circuit. A typical electrically-fired boiler is shown in Fig. 49.

Compressors. Where electro-pneumatic control gear or air braking is employed, one or more compressor sets are required to provide the necessary supplies of compressed air. These sets consist of a reciprocating or rotary compressor driven by a D.C. series or A.C. series commutator motor, the former deriving its power from either the overhead line or from the motor-generator set, whilst the latter operates from tappings on the secondary of the main transformer.

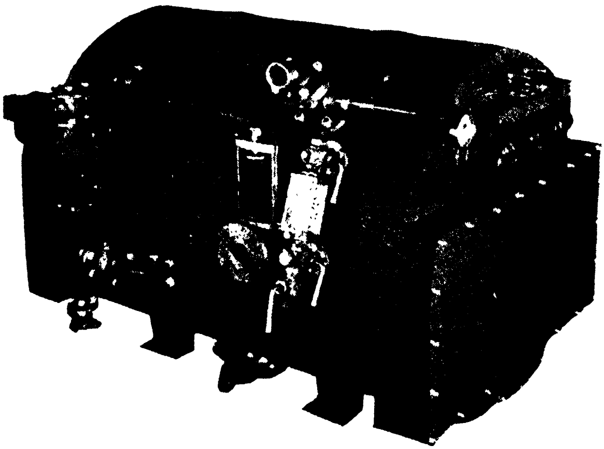


FIG. 49. Electrically heated boiler.

The reciprocating type of compressor has a number of cylinders with pistons connected to a common crankshaft driven either direct or through reduction gearing. Compression may be single-stage in which each cylinder is a separate compressor unit, or two-stage employing a large volume low-pressure cylinder feeding a smaller volume high-pressure output cylinder. Rotary compressors have an eccentric rotor with sliding radial blades running inside a hollow cylinder, air entering at the point where the largest clearance volume occurs and being aspired at the point of minimum clearance. Fig. 50 shows a typical rotary compressor in section.

Output pressures range from 70 to 120 lbs. per square inch and air is fed into a main reservoir from which the various air feeder

lines are tapped. Attached to this cylinder is the compressor control governor, which cuts out the compressor when the pressure has reached a certain value and starts it again at a minimum value. This governor makes and breaks the circuit by a double-break system employing two fixed fingers and a moving bridge carried

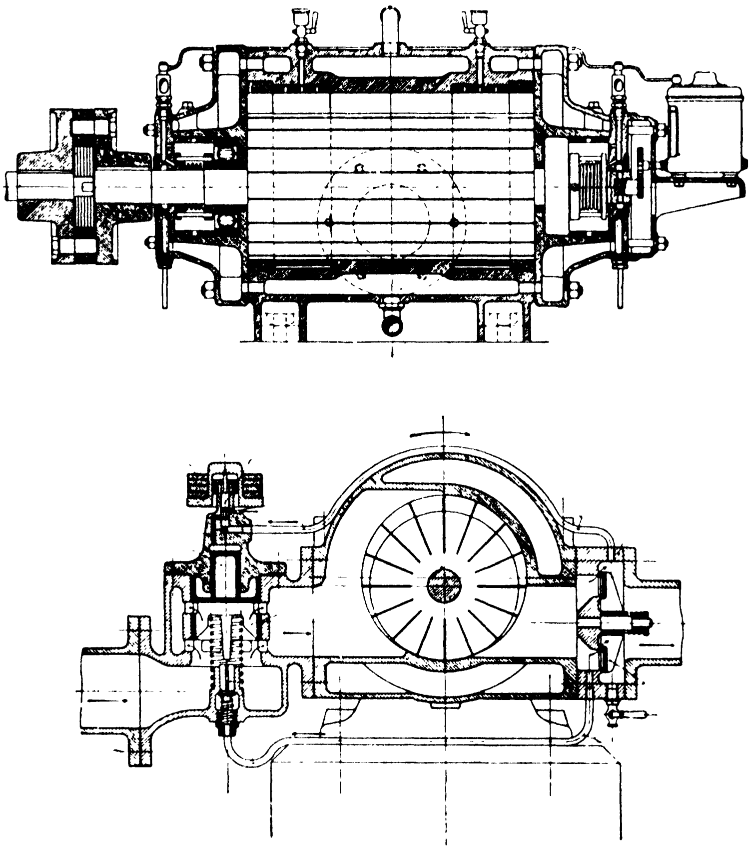


FIG. 50. Typical rotary compressor set in section.

by an air-operated piston, a pneumatic blow-out being provided for extinguishing the arc on rupture.

Exhausters. Where vacuum braking is to be utilised, one or two exhausters are required for ejecting purposes. These must be designed to fulfil two functions: (1) to be able to release the brakes throughout the train in a reasonable time: (2) to be able

to run continuously at a speed sufficient to maintain a vacuum of 20 ins. of mercury whilst the train is in motion. Two speed motors are normally used for this purpose, the additional speed being obtained by either shunting or tapping the motor field or inserting a resistance in the circuit. This action is carried out by contactors under the control of the driver's brake valve (see paragraph on Vacuum Braking).

Similar methods of driving are employed to those for a compressor, i.e. D.C. or A.C. series motors, although, in certain instances, shunt motors have been used on direct current and single-phase induction motors with a special starting winding on alternating current.

Various patented systems are on the market for exhausting, but the most popular is that similar to a rotary compressor with an eccentric rotor carrying radial blades which press against a hollow ground cylindrical perforated drum running freely inside a close-fitting steel casing. The blades sweep a crescent-shaped space, taking in air from the vacuum chamber at the low pressure, compressing it to above atmospheric and then releasing it. Remarkable efficiency and reliability are one of the advantages of such machines and their application is extensive.

Braking Systems

In addition to any electric braking system, an electric locomotive is always fitted with one of the two standard methods of braking, i.e. compressed air and vacuum. Frequently a combination of both systems is used, in which air brakes on the locomotive and vacuum on the train are operated under the control of the one driver's brake valve. In general, the two standard methods are elaborations of the following.

The Compressed Air Brake. Two types of compressed air brake are available—the direct-acting and the automatic. In the first case, air from the main reservoir is admitted direct to the brake cylinders under the control of a driver's brake valve of the self-lapping type, i.e. one in which the brake cylinder pressure corresponds to the relative position of the handle between the brake "off" and "on" positions. This, the simplest of all systems, is only suitable for locomotives used on duties where no train-braking is required, such as shunting and, in some countries, light freight traffic.

The continuous automatic air-brake is so called because, in the event of failure of any portion of the piping system throughout the train, or of the train breaking into two, the brake is automatically applied.

Fig. 51 shows the simplified air-piping connections for a continuous automatic air brake on a locomotive and a trailing coach. On bringing the locomotive into service, the driver closes the compressor control switch ; this action causes the compressor contactor to close, and hence starts up the compressor which charges the main reservoir until, when the maximum required pressure is attained, the control governor interrupts the supply to the compressor motor and thereby stops it. As pressure builds

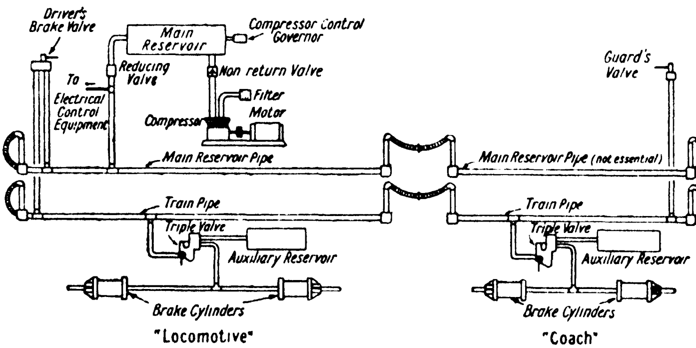


FIG. 51. Automatic air brake scheme for a locomotive and coach.

up in the main reservoir, the reducing valve admits air into the main reservoir pipe until the pressure therein reaches 70 lbs. per square inch. The driver's brake valve has five positions—" release," " neutral," " lap," " on," and " emergency." These make the following connections :

" Release " connects the main reservoir and train pipes together.

" Neutral " isolates all piping and is the position in which the brake valve is left when not in use.

" Lap " is sometimes combined with " Neutral," being a similar position.

" On " connects the train pipe to atmosphere through a discharge valve.

" Emergency " immediately destroys the train pipe pressure.

On the brake handle being set to the release position, the train

pipe and auxiliary reservoirs are charged to the same pressure as the main reservoir pipe, and meanwhile the "triple valve" discharges to atmosphere any air remaining in the brake cylinders. This valve is so designed that it operates on pressure difference between the train pipe and the auxiliary reservoir, and functions to admit sufficient air into the brake cylinders from the auxiliary reservoir, to bring the brake cylinder pressure to the same as that by which the auxiliary reservoir exceeds the train pipe. When the train pipe pressure rises above that in the auxiliary reservoir again, the triple valve again connects the train pipe to the auxiliary reservoir, thereby recharging it and at the same time it also discharges the brake cylinders to atmosphere. To make a normal service or traffic stop, the driver moves the brake valve to "on" for a time sufficient to drop the train pipe pressure some 10 lbs. per square inch and, on reaching this point, he returns the handle to the "lap" position. The triple valves throughout the train immediately react to give a brake cylinder pressure of 10 lbs. per square inch. Further reductions in train pipe pressure give greater braking efforts.

It will be noted that, when a brake application is made, the supply of air necessary for the brake cylinders is obtained from the auxiliary reservoir, a feature which ensures that, in the event of fracture of the train pipe or other similar failure, a full brake application will be made. Secondly, compared with the direct acting air brake, the strength of the brake application depends on the reduction of train pipe pressure and not on the relative position of the brake handle. Further, a partial release cannot be made; if an application is too heavy, the brakes must be released and then reapplied.

The Vacuum Brake. Compared with the air brake, the vacuum system utilises only one supply pipe running throughout the train. Brakes are released by exhausting the air from the train pipe to a vacuum of about 20 inches of mercury, and reapplied by reducing this vacuum. Strength of application is proportional to the reductions in vacuum and minute adjustments in the braking force can be easily made by increasing or decreasing the amount thereof.

A vacuum driver's-brake-valve has five positions:

(1) "Neutral," the "off" position in which the whole equipment is at standstill.

(2) " On," where the exhauster is at half-speed, the electrical stop valve closed, and the train pipe connected to atmosphere.

(3) " Lap " identical with " on," but with the train pipe isolated.

(4) " Run," with the exhauster at half-speed evacuating air from the train pipe.

(5) " Release," at which position the exhauster is evacuating at maximum speed.

The brake valve is thus a combined valve and controller, the electrical section being a small cylinder with segments attached, making contact with fingers and controlling the exhauster and stop valve.

The brake cylinder, frequently combined with the vacuum chamber, has its piston connected to the brake shoes by cranks

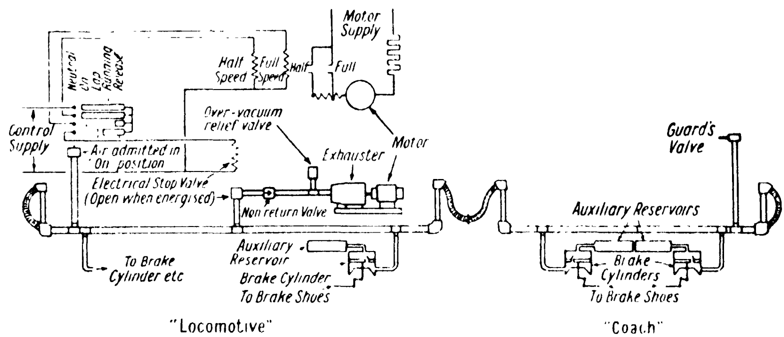


FIG. 52. Vacuum braking scheme for locomotive and coach.

and rodding. Air is extracted from the lower side of the piston by the connection to the train pipe and, as a result, the piston falls to the bottom of the cylinder, the brake-released position. By means of the small valve in the piston, air is then extracted from above the piston until the pressure throughout the cylinder is that in the train pipe. When the train pipe vacuum is reduced, the admission of air raises the piston in the cylinder, so applying the brakes. For shunting purposes, the brake can be put out of action by destroying the vacuum above the piston and so allowing it to fall to the bottom of the cylinder.

The method of operation employed with the vacuum braking system is first to release the brakes by setting the control handle to the release position, thereby running the exhauster at full speed. On reaching the necessary vacuum, the exhauster speed

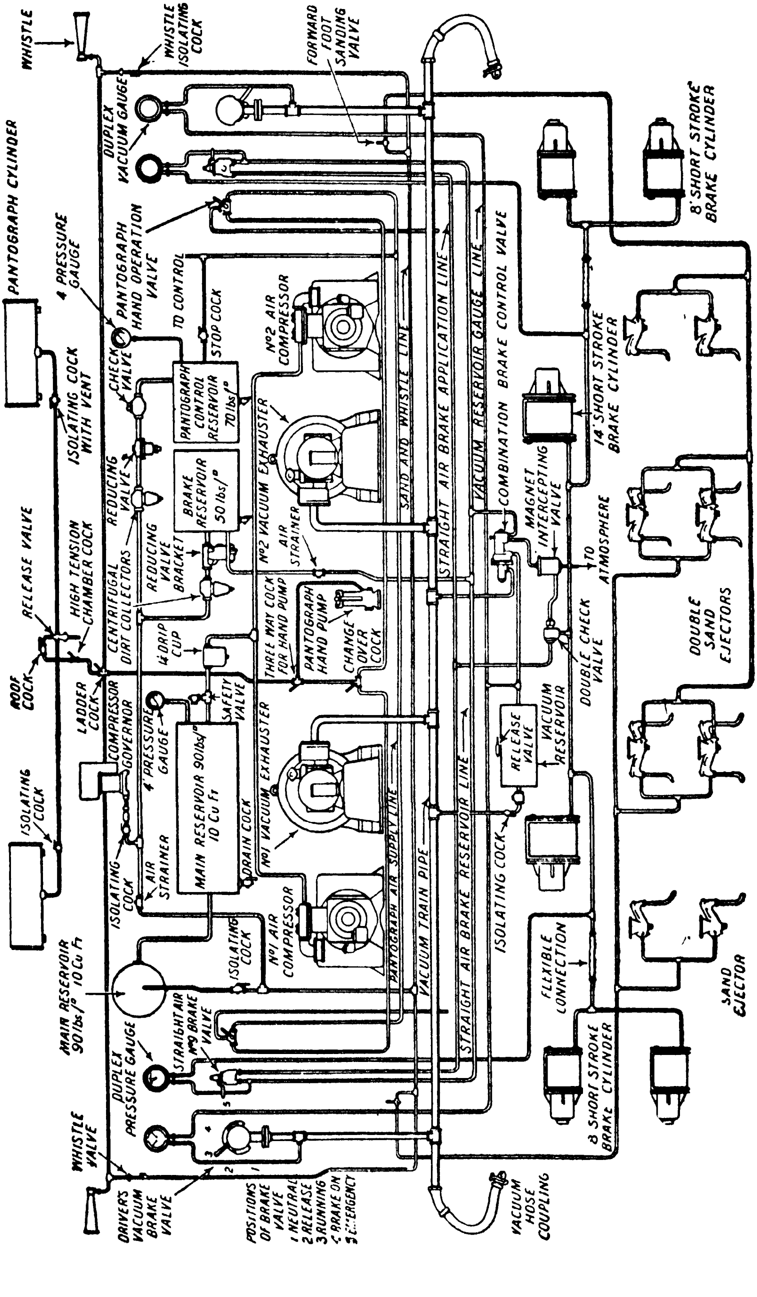


FIG. 53. Dual braking scheme for locomotive.

is then reduced to that necessary to maintain that vacuum, by moving the brake handle to the " run " position. Brake application is carried out by intermittent movement of this handle between " on " and " lap," so admitting quantities of air to the train line. In both these positions the exhauster is isolated from the train line, and a relief valve is provided to avoid excessive strain on the system. Reductions in brake pressure may be made, if required, by brief movements of the control handle between the "release " or " run " and " lap " positions.

To facilitate braking and increase the speed of propagation of brake application on long trains, a direct application valve may be fitted on each coach. This valve admits sufficient air from atmosphere direct to the brake cylinder to bring the pressure in that cylinder up to that in the train pipe, an action which considerably reduces the amount of air required to be admitted to the train pipe through the driver's brake valve for any given brake application.

Dual Systems. Locomotives for operation with vacuum-braked trains on which electro-pneumatic control gear is employed are frequently fitted with a dual system comprising a straight direct acting air brake on the locomotive and a vacuum brake on the train. The main system is identical with that shown earlier for the vacuum brake, but, instead of vacuum brake cylinders on the locomotive, a proportional valve is fitted which operates through a self-lapping pneumatic valve to make corresponding applications of the locomotive air brake to those on the train.

In certain cases where the locomotive is used for freight service not requiring a continuous train-brake, an additional handle is fitted on the combined vacuum-air brake controller which is used to operate the locomotive's air brake directly, so enabling the vacuum equipment, exhauster, etc., to be isolated when not required for train purposes.

CHAPTER FIVE

DIRECT CURRENT LOCOMOTIVES

WITH the object of affording as broad an outline as possible of the layout and construction of the many types of locomotive, a certain number have been selected and, in this chapter and the one following which deals with alternating current locomotives, these will be described and illustrated individually.

For reference purposes a list of those described follows :

Great Britain : Eastern Region Mixed-traffic locomotive.
Spain : 3000 h.p. double-bogie passenger locomotive.
New Zealand : Mixed-traffic locomotive.
France : A novel dual-voltage supply locomotive.
South Africa : Multiple-unit mixed-traffic locomotive.
India : Articulated heavy freight locomotive.
Japan : Combined rack and adhesion locomotive.
France : New passenger and freight locomotives.

Great Britain: Eastern Region Mixed-Traffic Locomotive. The locomotive illustrated in Fig. 54 is the first of seventy locomo-

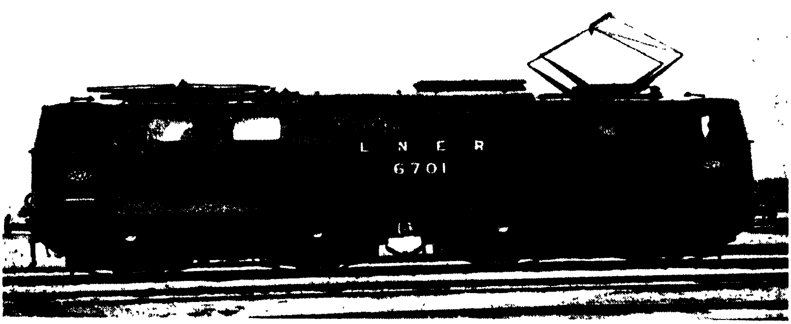


FIG. 54. British mixed-traffic locomotive.

tives which are to be constructed for the operation of all types of traffic between Manchester, Sheffield and Wath where lengthy

continuous gradients are encountered. The superstructure comprises an angle-iron framework enclosed by steel sheeting, a series of ventilating louvres being fitted down one side and a number of windows down the other, for illumination of the side corridor linking the two driving cabs. Opening from this corridor are five separate compartments, into which are built the control equipment, main starting resistance, train-heating boiler and two motor-generator blower sets, one generator being for control supply, etc., and one for regenerative excitation. Two sets of collector gear are situated on the roof, employing light-weight single-pan pantographs. The locomotive body is carried on two four-wheel bogies, articulated together and carrying buffing and drawgear at their outer ends, an arrangement frequently adopted with bogie locomotives, as it eliminates stresses from the superstructure, thereby permitting considerable reduction in weight. Four traction motors, two on each bogie, are of the nose-suspended axle-hung type, with a total one-hour rating of 1850 h.p., this figure being considered sufficient for the handling of all classes of train without assistance. Forced ventilation is supplied from the two blowers through flexible ducting. Electro-pneumatic control is employed utilising series-parallel combinations of two groups of two motors connected permanently in series, a circuit similar to that shown in Fig. 32 except that, as regenerative braking is installed, the extra change-over switches and circuits are included. A view of the partly-built locomotive and main bogies appears in Fig. 55. (For full details, dimensions, etc., refer to the Appendix, page 280.)

Spain: Double-Bogie Passenger Locomotive. Towards the end of 1944, the forerunner of a series of 3000 h.p. locomotives went into service on the 1500 volt Spanish National lines in the Pyrenees. Fig. 56 shows a plan with side elevation and cross-section. The running gear comprises two six-wheel trucks articulated together and fitted with buffing and drawgear. Each truck carries three traction motors which drive through single sets of gearing, and, in comparison with many locomotive designs, all three motors are mounted on the same side of their respective axles, this layout, together with a special flexible articulated joint between the trucks, being responsible for a considerable reduction in the weight transfer from front to rear axle experienced when moving heavy loads.

The superstructure is carried on bolsters on the trucks and is divided into three main compartments flanked down each side by corridors linking the driving cabs, an arrangement which provides ample access to the equipment for maintenance purposes. Centrally situated is the auxiliary machinery compartment containing exhauster and compressor sets, and a motor-generator blower unit comprising a motor driving a twin-auxiliary generator designed to supply the control and battery charging currents whilst the locomotive is operating under power, and traction motor field

Fig. 55. British Railways (Eastern Region) mixed-traffic locomotive during erection.

excitation when the regenerative brake is required. The blower fan is situated between motor and generator and 21,000 cub. ft. of air per minute are drawn from the interior of the locomotive, through the traction motors into a central air duct running longitudinally on the main frame. After passing through the main fan, the air is expelled through the starting resistance boxes, which are mounted adjacent to the roof in the auxiliary machine compartment. This system is unusual in that the customary method of force-ventilating motors is to blow the cooling air to them and not to use a suction system.

The auxiliary machine compartment is flanked by the two high-tension compartments containing the main circuit-breakers,

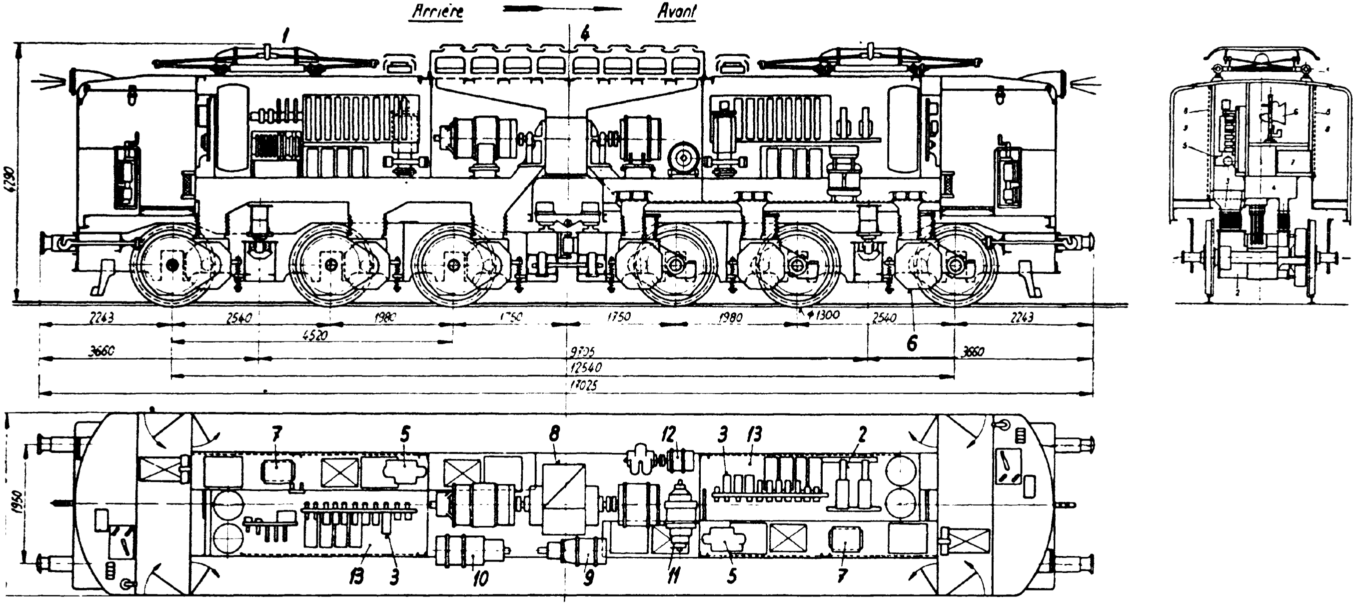


FIG. 56. Plan, elevation and section of 3000 h.p. locomotive—Spanish State Railway. (Dimensions in mm.)

Longitudinal View

1. Pantograph.
2. Main circuit-breaker.
3. Contactor group.
4. Resistance compartment.
5. Reverser.
6. Traction motor.
7. Inductive shunts.
8. Motor-generator-blower set.
9. Small exhauster.
10. Large exhauster.
11. Motor-compressor.
12. Reserve set.
13. Battery.

Cross-Section

1. Pantograph.
2. Traction motor.
3. Air intake.
4. Ventilating duct.
5. Reverser.
6. Contactors.
7. Battery.
8. Removable panels.
9. Side-corridor.

contactors, reversers, inductive shunts, etc., the general arrangement of these details being indicated in the diagrams. Electro-pneumatic control at 60 volts D.C. and 75–105 lbs. per sq. in. air pressure is employed in conjunction with series-parallel combina-

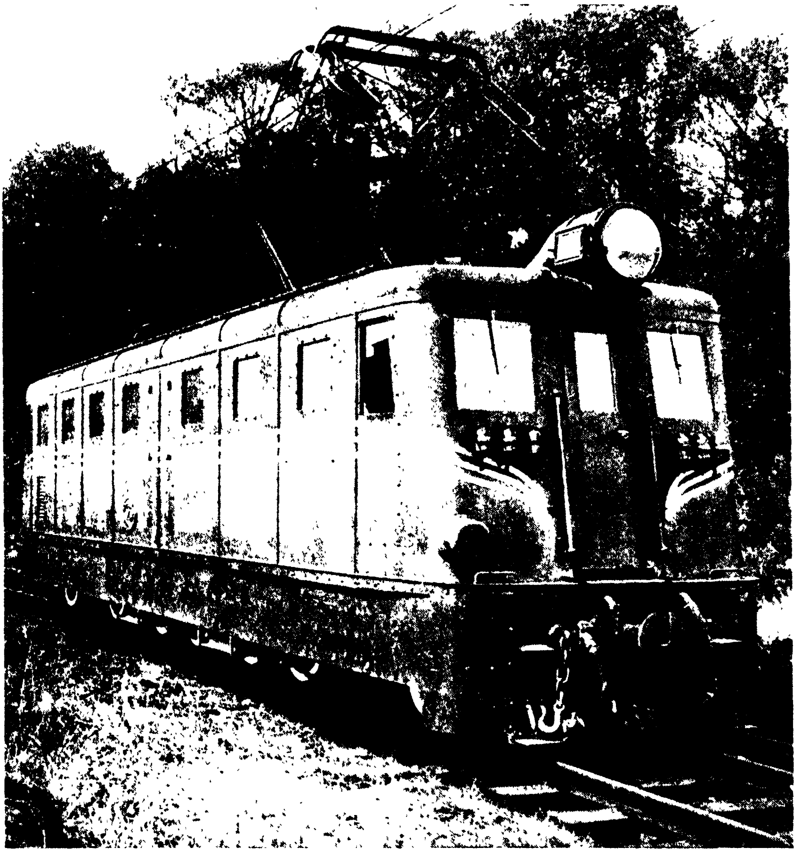


FIG. 57. 1240 h.p. mixed-traffic locomotive.

tions of two motor groups, each of which comprises three machines connected in series. Six running notches are provided, three with each combination, inductive shunts being used to obtain the reduced field values. Regenerative braking equipment is installed and may be utilised with either motor combination. It is brought into action by means of one electro-pneumatic five-position change-

over switch per motor group, this switch being arranged as a combined reverse and power-brake change-over unit.

During acceptance tests this locomotive demonstrated its ability by accelerating a train of 1200 tons from rest to a speed of 30 m.p.h. on an ascending gradient of 1 in 63, a remarkable achievement for its size, and justification of the running gear arrangement. (For full statistics, see Appendix, page 285.)

New Zealand : Mixed-Traffic Locomotive. The next locomotive described is a narrow-gauge (3 ft. 6 ins.) type in which the motors are rigidly mounted in the frame. It is designed to handle both passenger and freight traffic between Wellington and Paekakariki and is capable of handling loads up to 500 tons in weight up a gradient of 1 in 57. To enable this power to be developed, a 16 ton driving-axle load was decided upon, which necessitated the incorporation of a four-wheel bogie and a pony axle into the design, in order to carry the necessary equipment whilst keeping within this loading limit. The wheel arrangement is, therefore, $2\text{–}D_0\text{–}1$, four motors with a total one-hour rating of 1240 h.p. being employed, one driving each axle and geared to provide a maximum speed of 55 m.p.h. In working order, the locomotive weighs 88 tons.

Fig. 58 shows a plan and elevation of the locomotive in which the main dimensions are indicated. The main frames are built up of two longitudinal rolled steel side-plates riveted at each end to cast-iron drag castings which carry the central buffer drawgear. Attached to this main underframe is a steel T-section framework which carries the steel sheeting making up the superstructure.

To provide the flexible drive necessary between the main motors and the locomotive driving wheels, the torque of each motor is transmitted through a quill and cup mechanism, in which the motor is rigidly bolted to the main frame above the driving axle, and drives the quill through a 19 to 71 spur reduction gear shrunk on to one end of the quill. The quill-shaft runs in bearings cast integral with the base of the motor frame and by this arrangement the whole weight of the drive except wheels, axles and axleboxes is springborne. Each pair of motors is ventilated by a separate motor-blower set operating directly from the 1500 volt supply and capable of delivering 3000 cubic feet of air per minute, the incoming air being drawn through filters and delivered to the motors through ducting, after which it is discharged out to the

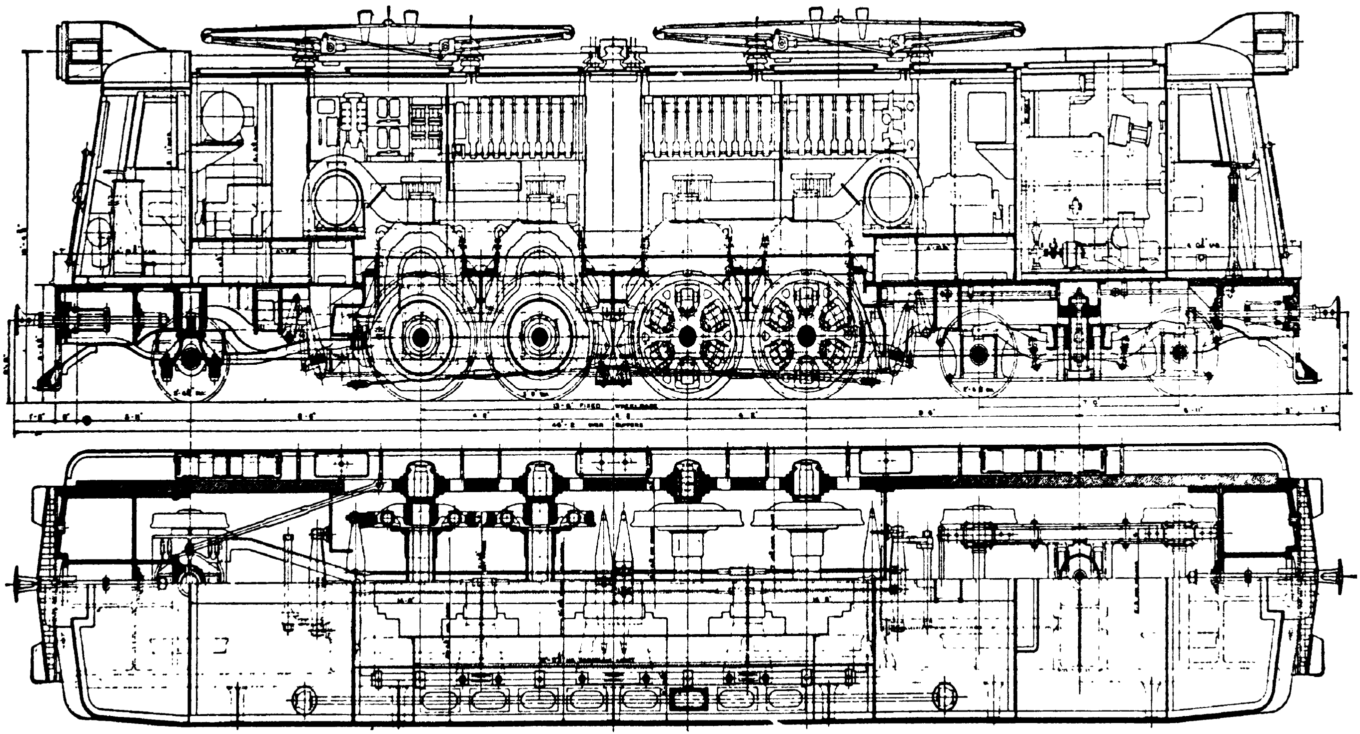


FIG. 58. Plan and elevation of mixed-traffic locomotive. (New Zealand Government Railways.)

track. Fig. 59A shows an interior view of the locomotive in which the arrangement of this ducting can be clearly seen.

Electro-pneumatic control at 120 volts is used, the power and control circuits being identical with those shown in Fig. 32 except that no rheostatic brake is incorporated. The control gear and main starting resistance boxes are arranged on opposite walls of a high-tension chamber running the length of the locomotive and also housing a 4 KW motor-generator set, the two blower sets and

FIG. 59A. Interior of H.T. compartment.

a current limiter. A corridor linking the two driving cabs runs along the side of the locomotive behind the control-equipment frames and, by means of a series of detachable covers opening from this corridor, access to the rear of the apparatus for maintenance purposes is greatly facilitated, a fact amply demonstrated in Fig. 59B, which shows a view of the corridor with the covers removed. The main resistance boxes are enclosed in a chamber which is ventilated by the induced draught obtained by providing openings in the floor and a series of ventilators in the roof.

Train heating is provided by an oil-fired water-tube boiler situ-

ated between the driving cab and high-tension compartment at the four-wheel bogie end of the frame and arranged to supply 250 lbs. of steam per hour at a pressure of 40 lbs. per sq. in., when required. Operation is entirely automatic from the closing of the control switch, thermal safeguards being employed to protect

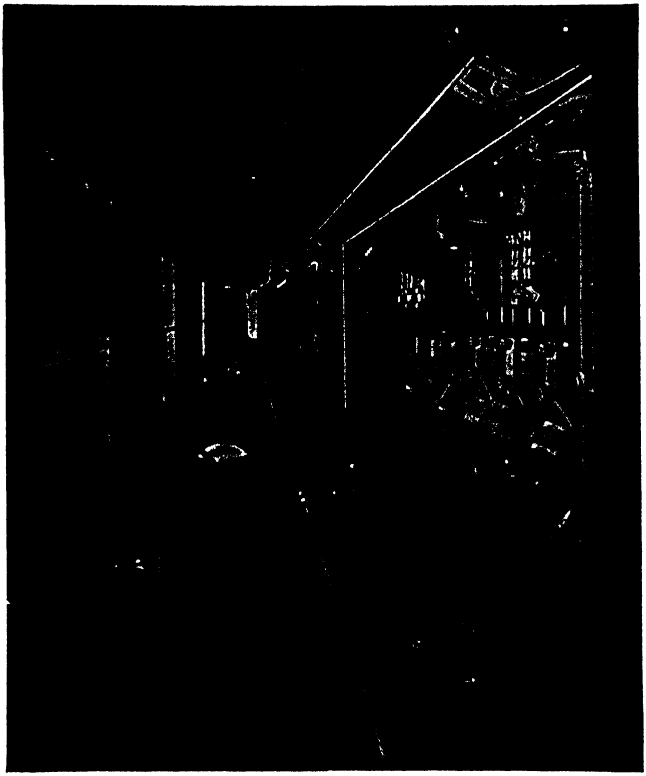


FIG. 59B. Side-corridor showing accessibility of control-gear.

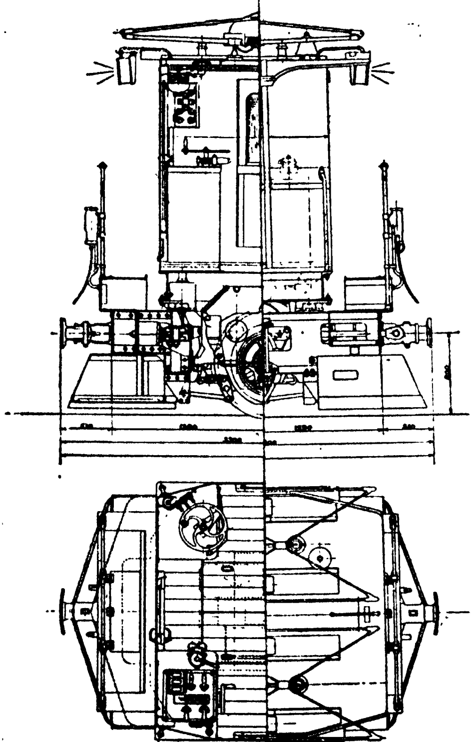
the equipment. Sufficient water and fuel are carried in 400 and 50 gallon tanks respectively to enable the boiler to steam continuously for approximately four hours.

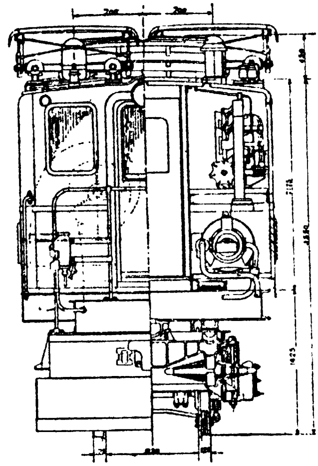
Current is collected from a 1500 volt overhead trolley wire by two lightweight pantographs, but, owing to the minimum contact wire height being only 12 feet, it was necessary to mount these in wells situated in the roof of the locomotive.

In addition to the locomotive just described, a modified but similar type was also built which incorporated rheostatic braking equipment. Additional resistance boxes were necessary to provide for this and, as the extra accommodation required for these was lacking, the heating boiler was eliminated as not necessary on the short section over which these locomotives were designed to operate. Certain other modifications designed to improve the ventilation of the braking resistance were also incorporated.

FIG. 60. Locomotive for twin-supply system.

France: Dual-Voltage Locomotives. A novel type of double-bogie locomotive is illustrated in Fig. 60. It was designed to operate over the metre-gauge line between St.-Georges-de-Commiers, La Mure and Gap in South-Eastern France on which two differing types of power supply are employed. From St. Georges to La Mure (31 kilometres) a 2400 volt D.C. supply is provided by means of two overhead wires, one for supply and one for return, the centre point of the system being earthed, an arrangement which limits the voltage between each trolley wire and earth to half that of the supply. From La Mure to Gap (80 kilometres) a single-wire system with running rail return is used, the pressure being 2400 volts as before and the wire offset to a position corre-





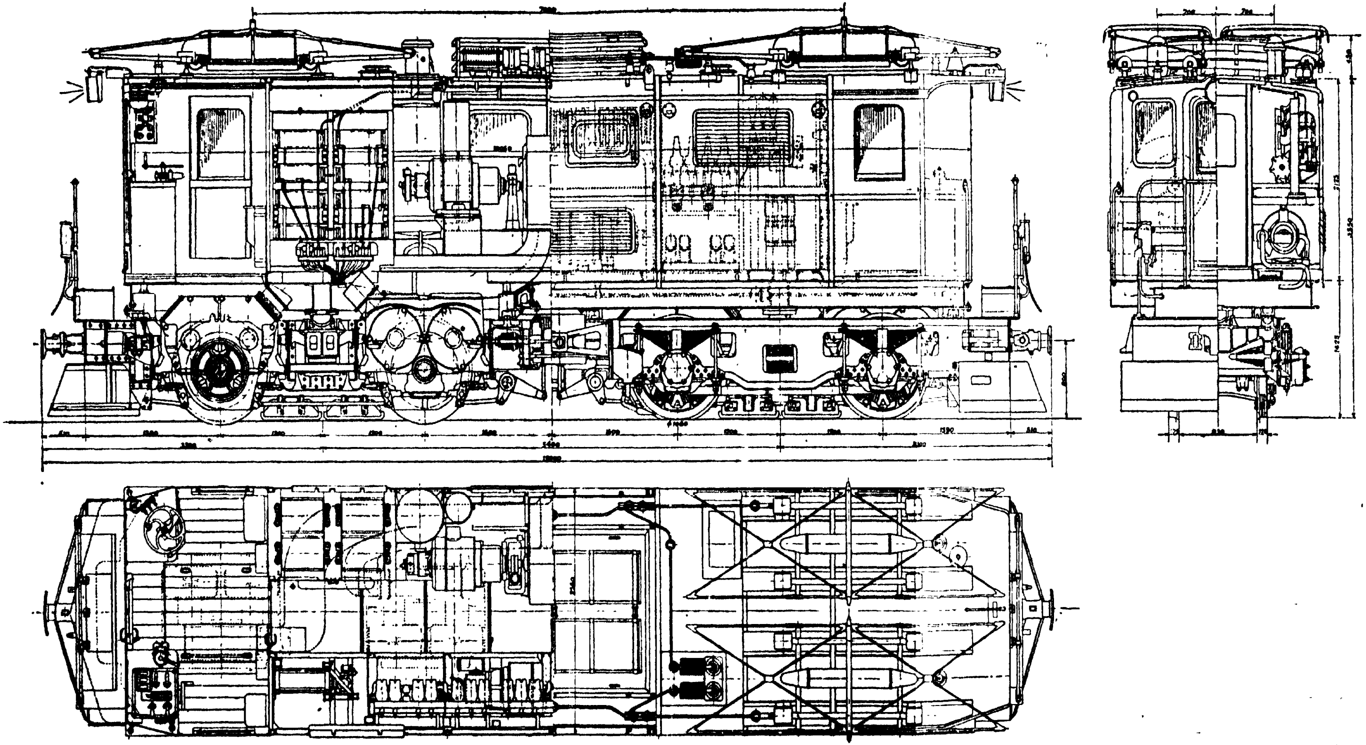


FIG. 61. Plan and elevation of twin-supply locomotive.

sponding to that of the supply wire on the twin-wire section. The electrical equipment of the locomotive is insulated from earth and incorporates a change-over switch and two pairs of narrow pantographs arranged so that, when operating over the twin-wire portion, both pantographs of a pair are used, no connection at all being made to earth, but, when operating over the single-wire section, the return pantographs are lowered and, by means of the change-over switch, connection is then made to the running rails.

The two bogies are articulated together and carry the combined buffer-drawgear at their outer extremities. Four twin-armature

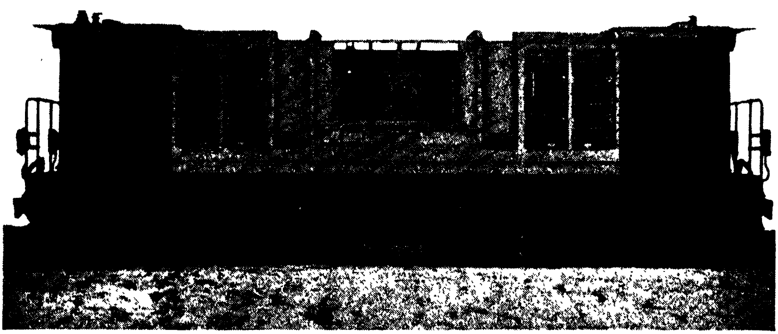


FIG. 62 (i). 920 h.p. twin-supply locomotive.

motors are rigidly attached to the bogie frames and a flexible drive of the Sécheron spring pattern is used to transmit the torque to the driving axles, a most unusual arrangement for this type of locomotive. The four motors are permanently connected in parallel, each pair of armatures being connected in series and having a one-hour rating of 230 h.p. with forced ventilation at 2300 cubic feet of air per minute. They are geared to provide a maximum speed of 25 m.p.h., quite sufficient for the steep gradients and sharp curves which predominate over the route. The weight of the locomotive in working order is 60 tons.

The superstructure is arranged with a central gangway joining the driving cabs together and, mounted at one side of this corridor, is the main motor-generator blower set, flanked by two force-

ventilated starting resistance chambers. On the opposite side are a number of compartments containing the five-position reverser/power-brake change-over switch, the main circuit breakers and a group of mechano-pneumatic contactors operated from the master

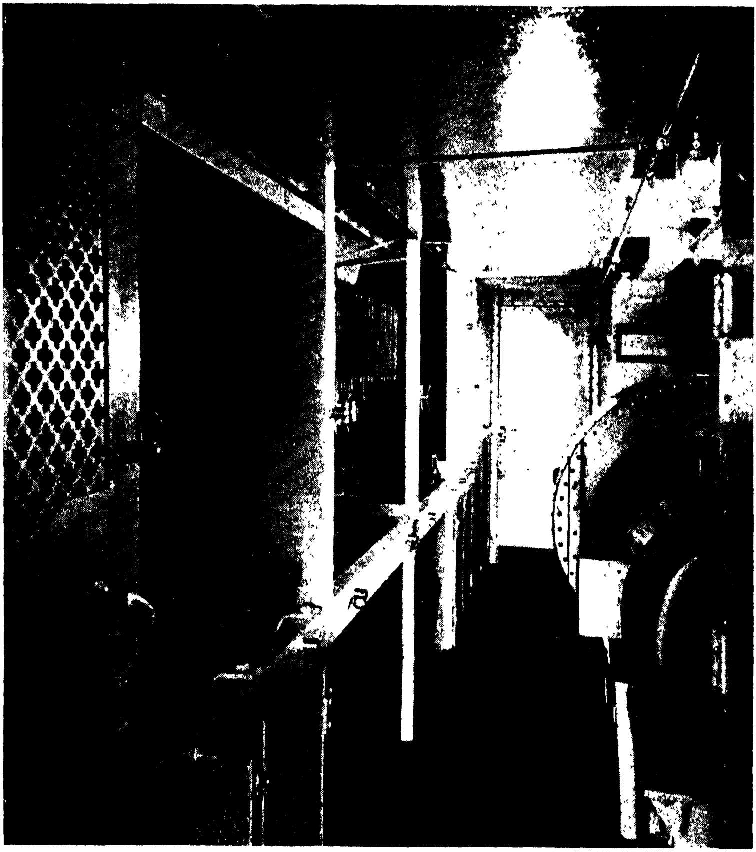


FIG. 62 (ii). 920 h.p. twin-supply locomotive.

controller through a geared camshaft, these enclosures being designed to prevent access to this high-tension control-gear except when the pantographs are depressed. 37 accelerating notches are provided, only the last of which is a running position and a rheostatic braking system is incorporated with 34 braking positions, each including crossed-field excitation to maintain stability. A

main circuit breaker comprising two contactors is installed in both supply and return leads, and functions so as to limit current rush and contactor duty by sequence opening of the contactors, as described in Chapter Three.

Fig. 61 shows a plan and elevation of the locomotive and Fig. 62 a view during construction and one of the interior. Full details and dimensions appear in the Appendix, page 279.

South Africa: Multiple-Unit Mixed-Traffic Locomotives. The Durban–Pietermaritzburg–Glencoe–Volksrust and branches section of the Natal Railways is operated by some 180 locomotives of the double-bogie (B_0+B_0)[1] type, each weighing 66 tons and developing 1200 h.p. on the one-hour rating. 95 of these locomotives were supplied in the original scheme about 1926 and, since 1936, due to various extensions of the electrified section, a further 85 have been delivered, spread over a five-year period. The earlier locomotives have frequently been described and illustrated in other publications and, whilst the later machines are somewhat similar, a number of modifications and alterations have been made in both the mechanical and electrical equipment, which justify a description being included here.

Two bogies, articulated together and fitted with automatic drawgear, carry the four axle-hung nose-suspended traction motors and, except for the motor axle-way bearings, all others (i.e. armature and axle-box) are of the roller anti-friction type. The drive to each axle in the original locomotives was from a pinion on the armature shaft to a gear wheel solidly attached to the road-axle, but, to reduce shocks and cushion the drive, it was decided to use spring-gear wheels on this later type. Forced ventilation for the traction motors is supplied by two blowers driven from the motor-generator sets, one of which is mounted over each bogie to reduce the ducting required to a minimum. The two M.G. sets are rated at 16 KW and 28 KW, and supply the control and auxiliary equipment and the regenerative brake excitation respectively. Each is driven by a double-commutator motor, designed to operate directly from the 3000 volt trolley wire supply. A compressor and an exhauster are included in the equipment, the former to supply compressed air for operation of the control-gear and the straight air brake on the locomotive; the latter to provide the vacuum necessary for train braking.

[1] See Appendix for explanation of the standard method of wheel classification.

The high-tension equipment is situated between the two M.G. blower compartments and is divided between three separate

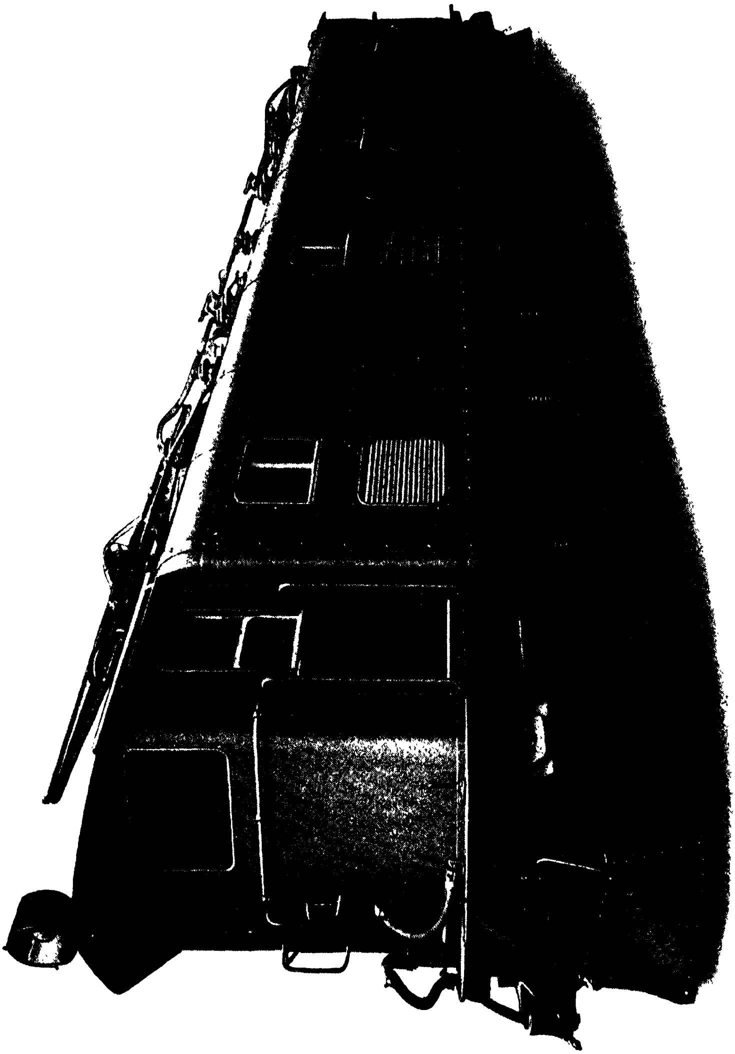


Fig. 63. 1200 h.p. locomotive for South Africa. (1936 delivery.)

sections, viz. a central compartment containing all contactors, relays, and the motor combination, reverser and power-brake change-over switches (all of the drum type); and two small

resistance chambers, one at each end. These latter are cooled by induced draught, air being admitted through mesh-covered holes in the floor and rising to pass away through four ventilating cowls in the roof of each compartment. They are entered by means of

FIG. 64A. Main equipment frame.

dust-proof sliding doors from the main equipment compartment, access to this latter being through a sliding door opening from the side corridor which links the driving cabs. All the control gear is mounted on two frames facing each other situated transversally across this compartment, and either frame can be removed complete and another substituted when overhaul becomes necessary,

a feature which considerably reduces the time of a locomotive out of traffic for maintenance purposes. One of these control-groups and a resistance compartment are shown in Fig. 64. Electro-pneumatic control is employed in conjunction with series-parallel combinations of two motor-groups, each of which com-

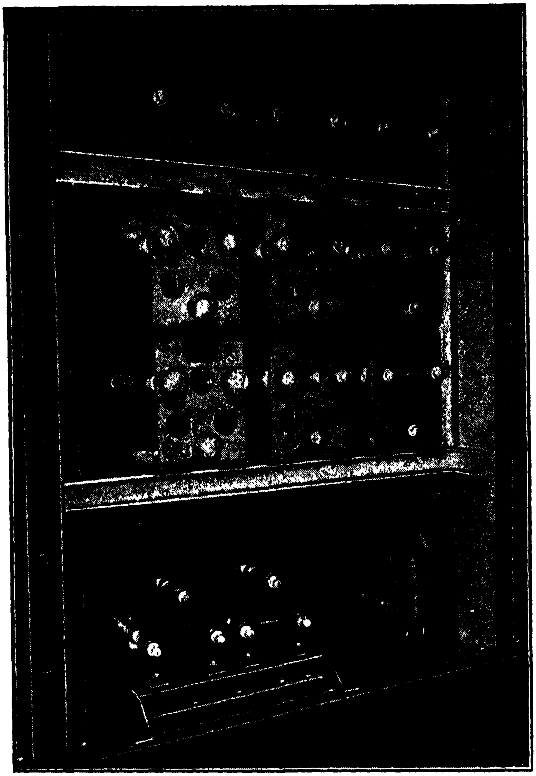


FIG. 64B. Resistance compartment.

prises two machines connected permanently in series. Both driving cabs are arranged with the controller, brake valve, etc., at the right-hand side and, in order to provide a large clear look-out, several of the instruments are mounted edgewise. As the locomotives are equipped to operate in multiple with up to four units, an end gangway door is centrally placed in each cab to permit the assistant driver to pass from one unit to the next.

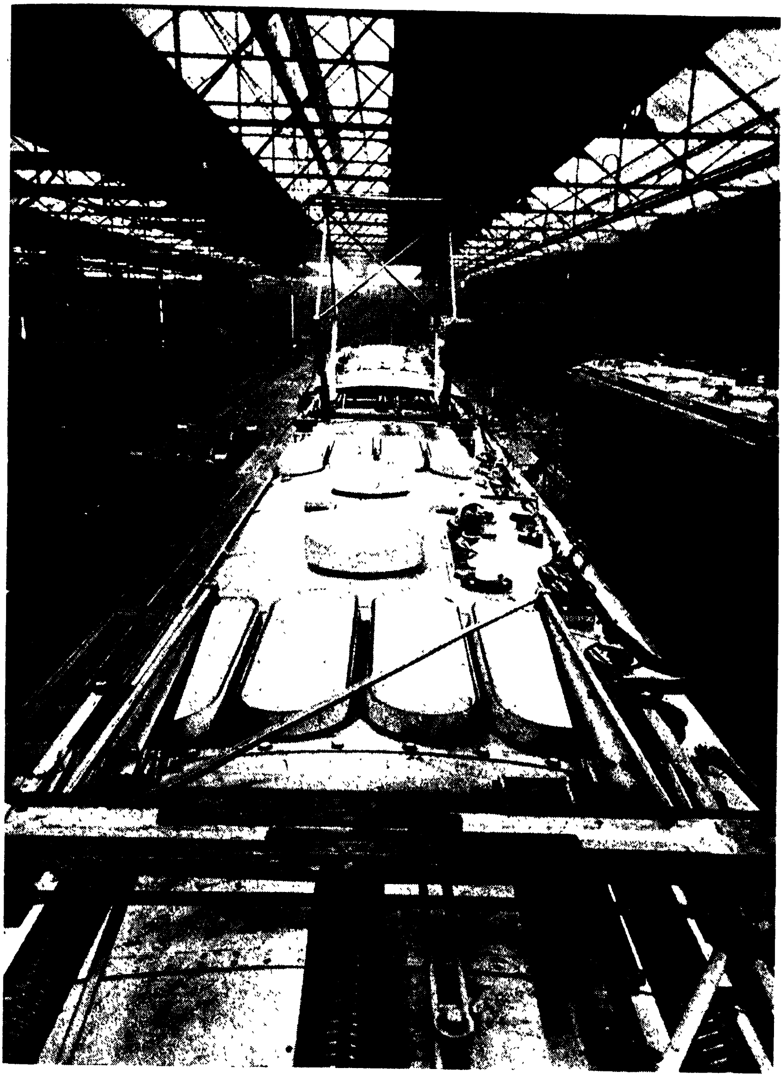


FIG. 65. Roofgear of S.A.R. locomotive.

Current is collected by two single-pan pantographs which exert a contact wire pressure of 16 lbs., a considerable reduction from that in the earlier locomotives and one making for a decrease in wear of the trolley-wire. The roofgear, pantograph, etc., are

shown in Fig. 65; note the lightning arrestor gear, choke coil, pantograph isolating switch and resistance chamber ventilating cowls.

For statistical details, see the Appendix, page 286.

India : Articulated Freight Locomotive. The locomotive illustrated in Fig. 67A is a 120 ton 2600 h.p. machine, which operates on the Great Indian Peninsula Railway (Appendix, page 281). To provide flexibility, the design caters for two independent driving bogies with the body slung between them. Mounted on each bogie are two 650 h.p. motors, which drive a common jackshaft through twin helical gearing, a collective drive being employed in which the six wheels are coupled together and driven by connecting rods from crankpins attached to the jackshaft. The motors are forced-ventilated by two blower-fans, one mounted on top of each frame and both driven by one centrally-situated motor. A certain amount of control apparatus for reversing and field weakening is mounted at the outer end of each bogie, in order to reduce the number of leads passing through the flexible joints between the bogies and the main frame. All this equipment is enclosed beneath a removable hood, the height of which is arranged to allow a clear view above it from the driver's cab at the front of the main superstructure.

One main longitudinal member runs along the centre line of the body and has supplementary side-members and bracings which support the framework of the superstructure. This member connects the two driving units, to which it is attached by spherical pivots supported in housings and is the medium through which the tractive effort is conveyed. The inner ends of the bogies are also connected by a system of rods and bell crank levers which tend to minimise wear on both wheels and track when negotiating the sharp curves which abound on the hill-country sections. Driving cabs are provided at each end of the main body, and are inter-connected by a side-corridor from which opens the main high-tension compartment, this being sub-divided internally into resistance and control equipment sections. The resistance chamber is ventilated by induced draught and is situated in the centre of the compartment, where it is flanked by the two control-gear sections, each adjacent to the driving-bogie with which it is concerned, an arrangement chosen to isolate the two halves of the equipment as much as possible. Various items of auxiliary

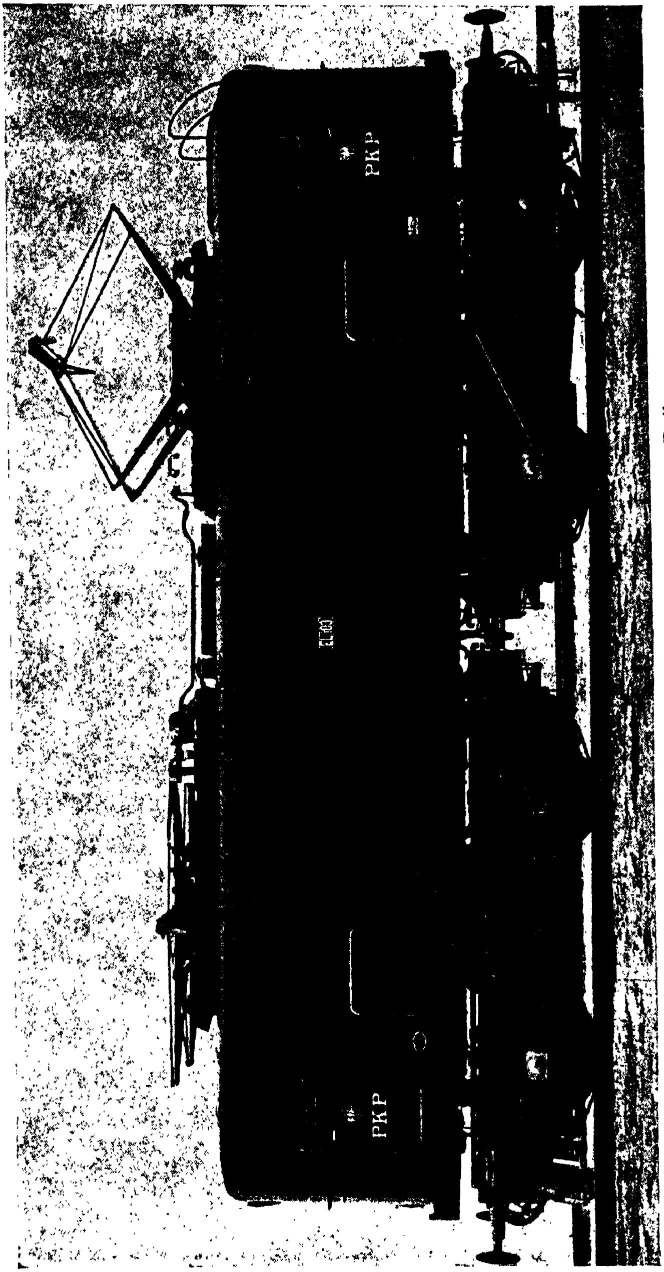


FIG. 66. Mixed traffic locomotive—Polish State Railways.

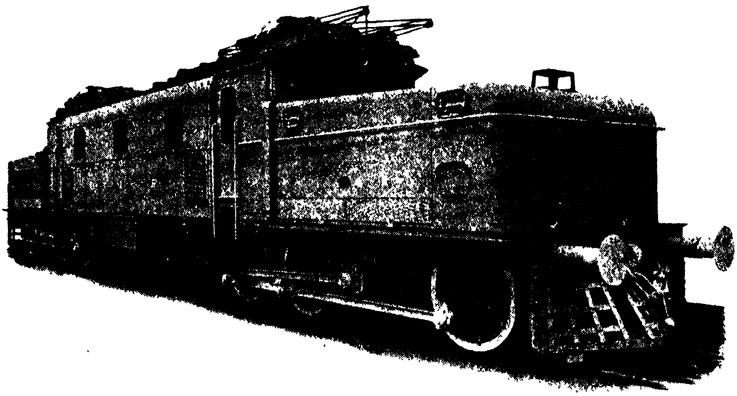


FIG. 67A. Articulated freight locomotive.

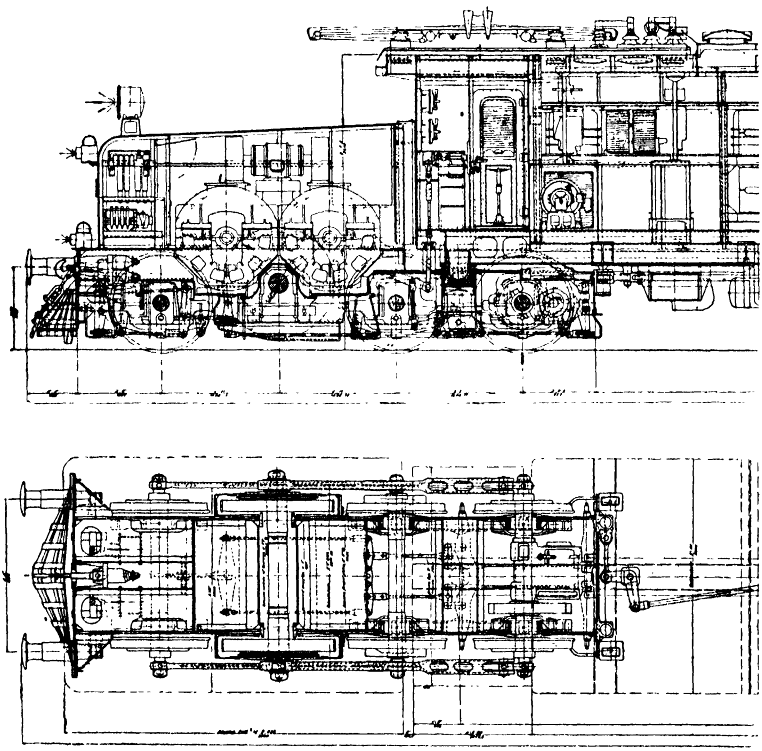


FIG. 67B. Diagrammatic layout of driving bogie-articulated freight locomotive.

machinery are also mounted in these outer sections of the high-tension chamber.

Current is collected from a 1500 volt overhead trolley-wire by two double-pan pantographs and, as the motors are each wound for full-line voltage, double-series-parallel control is employed. Electro-pneumatic equipment is installed and is arranged to provide nine running positions, three in each combination,

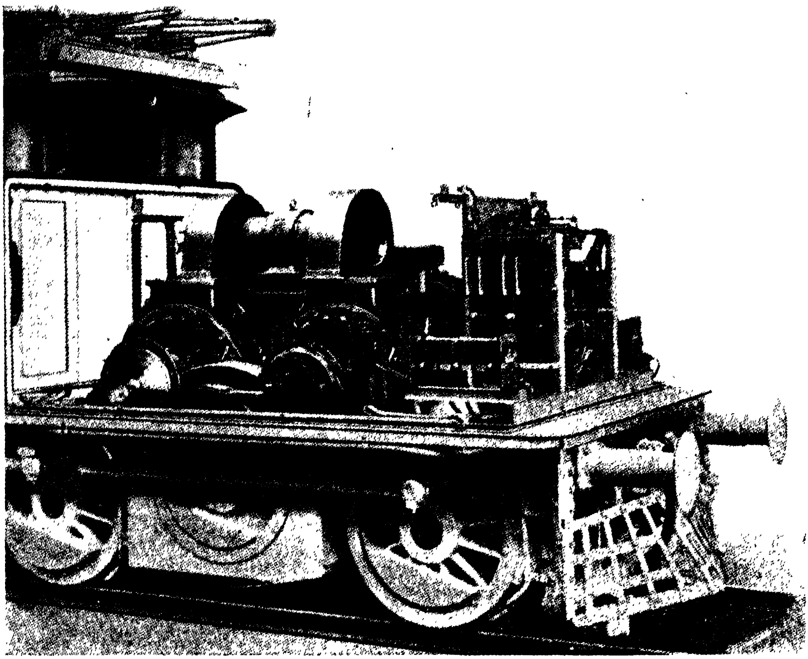


FIG. 67C. Driving bogie with hood removed.

together with regenerative braking, this latter being effective at speeds from 8 to 35 m.p.h. Excitation for the traction motors during braking is provided by a small axle-driven generator at the inner end of the bogie.

A plan and elevation of one driving bogie appear in Fig. 67B.

Japan: Rack and Adhesion Locomotive. The locomotives described in this section were built twenty years ago, but have been selected for description as an example of a rack and adhesion

machine fitted for both overhead and conductor rail power supply. They were designed to fulfil the following conditions :

(*a*) A tractive effort of 26,400 lbs. at 9·7 m.p.h. on a 1 in 15 gradient was required, two-thirds of this to be developed at the rails and one-third on the rack using three motors rated at 260 h.p. each.

(*b*) Electric braking equipment was to be installed, capable of braking half the weight of a 160 ton train when descending the

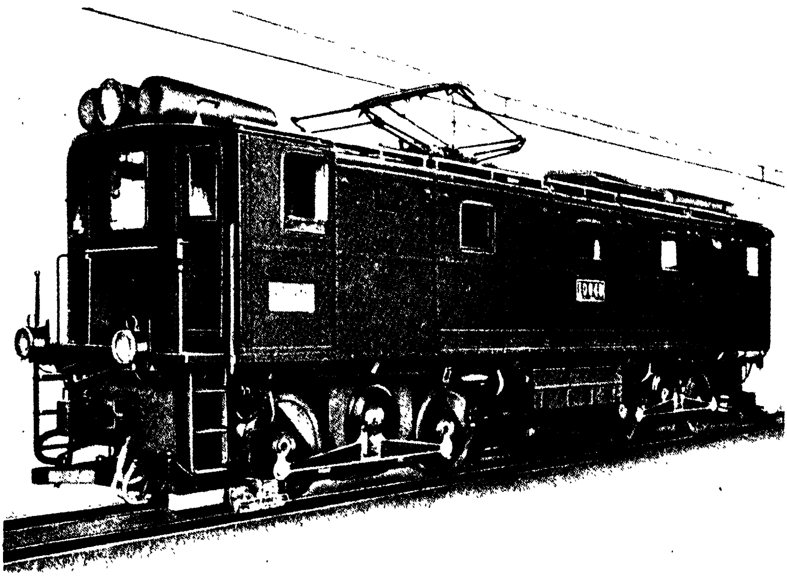


FIG. 68. Combined rack and adhesion locomotive.
(*Brown-Boveri Review.*)

steepest portion of the rack at 10 m.p.h. and of braking the whole weight of 160 tons when descending a 1 in 40 adhesion section at 15 m.p.h.

The complete locomotive, which weighs 59 tons in working order, is shown in Fig. 68. It consists of two adhesion driving bogies between which is arranged a framework which carries the rack-pinion drive, special double axle-boxes of cast steel being provided on the inner axles of each bogie with bearing plates supporting the framework. Each adhesion bogie is built up of sheet steel plate held together by the buffer beams, motor supports

and cross-braces, and carries the superstructure on a main pivot, two side pivots and a roller bearing. One traction motor is mounted on each bogie and power is transmitted from the armature shaft to the driving wheels by means of a geared jackshaft with inverted "Scotch Yoke" coupling rods. The rack-drive framework is fabricated from steel plates stiffened by castings in the centre and at the ends, and supports the rack motor with its associated driving gear. This consists of two triple rack pinions of the ABT-bar type driven by two sets of double-reduction gears

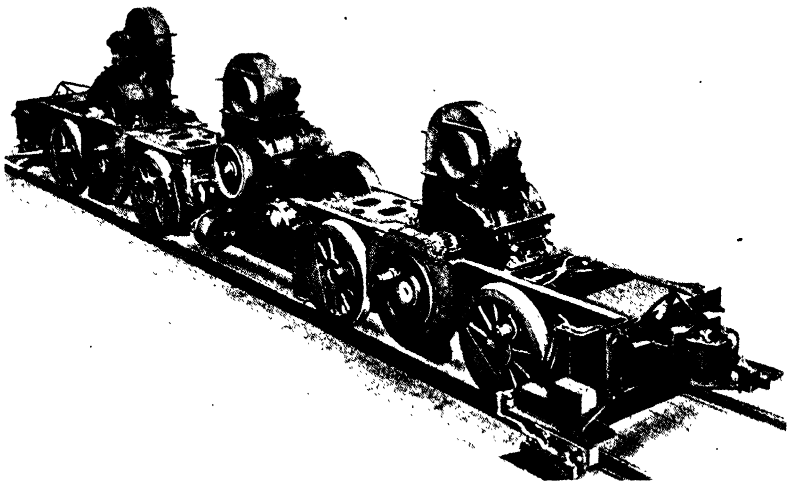


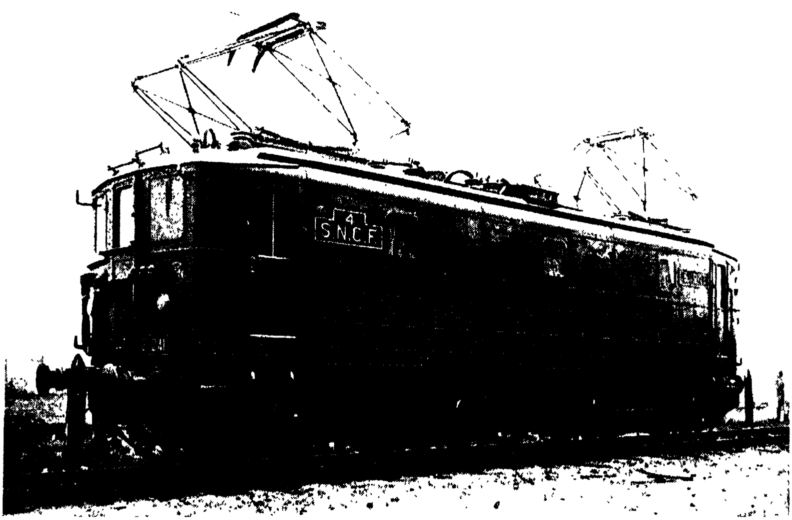
FIG. 69. Running gear of rack and adhesion locomotive.
(*Brown-Boveri Review.*)

from a single pinion on the motor shaft, and incorporating an overspeed device which is arranged to apply a brake-band on a drum attached to the motor-shaft, should the speed exceed 12 m.p.h. on the rack sections. Each traction motor has an independent motor-blower set, mounted on the upper surface of its frame, which provides 2850 cub. ft. of air per minute for cooling.

The general layout of motors, bogies, etc., is shown in Fig. 69 and at the outer end of each bogie can be seen two collector shoes of the under-running type, one at each side, these being utilised for current collection on third rail sections of the system.

A driving cab is provided at one end only, the width of the remainder of the superstructure being reduced to permit observa-

(i)



(ii)

FIG. 70. French passenger and freight locomotives.

tion when the locomotive is operating in the reverse direction. The three motors and blower units project some five feet into the superstructure, and in the two spaces intervening are mounted the control equipment frames and main starting resistance, the latter being forced-ventilated in order to provide for dissipation of energy during rheostatic braking. A pantograph is mounted on the roof adjacent to the driving cab for use with an overhead trolley wire where required.

When operating on the adhesion section, series-parallel control with bridge transition is employed, in conjunction with field-weakening, this giving six running positions. When running on to or off the rack sections, the fields of the three motors are connected in series and the armatures in parallel, an arrangement which synchronises the road-wheels and rack-pinions, and hence allows the latter to engage the rack without shock. On the rack-section, two motor combinations may be used ; first, the two adhesion motors in parallel are connected in series with the rack-motor ; then, all three motors are connected in parallel, a total of 14 accelerating positions being available.

France: Passenger and Freight Locomotives. Fig. 70 shows examples of two types of locomotive built in France during the German occupation period. One is a 2–D_0–2 express passenger locomotive with frame-mounted motors which drive the four axles individually by the Buchli link system, the external gear-cases of these drives almost obscuring the driving wheels. Power is supplied at 1500 volts and camshaft-contactor control with three motor combinations is employed, a total of 15 running notches being available. The second illustration shows a typical double-bogie goods locomotive of 1830 h.p. which conforms in general to standard practice in this direction. Full details, as supplied by the French National Railways, are quoted in the Appendix on page 279.

CHAPTER SIX

ALTERNATING CURRENT LOCOMOTIVES

In the previous chapter the descriptions of the locomotives are preceded by a list of those concerned for rapid reference purposes. Repeating this procedure, the following units are to be described :

U.S.A. : 3750 h.p. and 4620 h.p. passenger locomotives.
U.S.A. : Articulated mixed-traffic locomotive.
Switzerland : Light and medium-power passenger locomotives.
Switzerland : 12,000 h.p. mixed-traffic locomotive.
Switzerland : 1–D_0–1 multiple-unit locomotives.
Switzerland : Articulated mixed-traffic locomotive.
Switzerland : Double-bogie passenger locomotive.
Switzerland : Freight and shunting locomotives.
Sweden : Standard mixed-traffic locomotive.
Sweden : Experimental locomotives with individual axle-drive.
Germany : Brief details of the latest types of locomotive.
Italy : Typical three-phase locomotives.

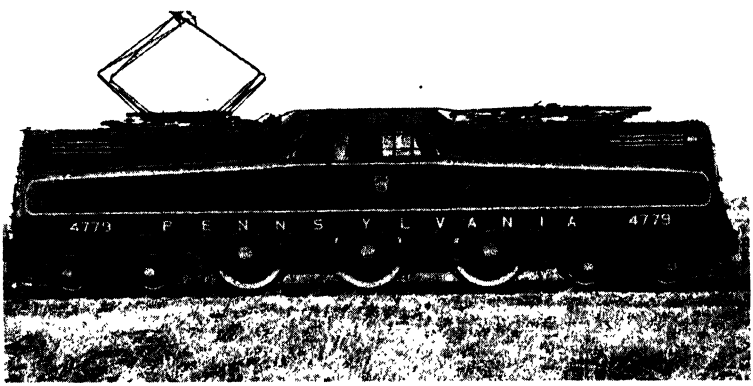


FIG. 71. 3750 h.p. U.S. Passenger Locomotive (Class P5A).

U.S.A.: Passenger Locomotives for High-Speed Service, Fig. 71 shows a 3750 h.p. locomotive of which 32 are in service for high-speed passenger workings on the Pennsylvania Railroad.

with a further 58 non-streamlined machines of similar construction for freight workings. The main chassis comprises a single casting, with oil, air and water reservoirs cast integrally which carries under its central section the three driving axles running in roller bearing axle-boxes and is supported at its outer ends by two four-wheeled guiding bogies. Three twin-armature motors are mounted on this frame, a three-point suspension being employed and each motor drives one road-axle through single-reduction gearing and a flexible drive of the quill and cup type. The driving wheel centres are of cast steel, and at one side of the locomotive have special pads located on the eight spokes to receive the driving torque from the spring-cups which are attached to projections on the quill-shaft gear-wheel.

A single driving cab is placed in the centre of the superstructure, the remainder of which has tapered set-back sides and a rounded front in order to provide a clear view in each direction, an arrangement which produces a pleasing streamlined effect. The whole superstructure is built up of aluminium sheeting on a welded steel frame, and encloses the main transformer, control apparatus, oil-fired heating boiler and other equipment under the two hoods, access into which is provided by central corridors opening from the driving cab. Attached to the top of each hood is a light-weight double-pan pantograph which collects power from an 11,000 volt 25 cycle supply.

Each pair of armatures is permanently connected in series and the three groups so formed are fed from nine tappings on the main transformer secondary which gives a maximum output of 960 volts. Preventive coils and reactors are used to eliminate short-circuiting and current surges in the secondary winding and motor-circuits during tap-changing. Wheel-slip relays are arranged in the motor circuits which function so that a speed differential of 8 m.p.h. between axles is indicated to the driver and one of 20 m.p.h. is effective in opening all power circuits.

Four single-phase induction motor-blower sets are included in the equipment, one for each traction motor and one for transformer cooling, this latter being arranged to drive in addition a small D.C. generator which provides the supplies for battery charging and for operation of the control-gear.

The 4620 h.p. articulated locomotive, introduced in 1935, has proved extremely versatile and its ranks have swollen to 139 in

the last few years. Illustrated in Fig. 72, it is a development of the earlier class P5A locomotive and was chosen after comparative tests with other experimental types in which it proved superior in operation and riding qualities.

The running gear consists of two cast-steel main trucks, each fitted with three driving axles and a four-wheeled guiding bogie at the outer end. These two trucks are articulated together by a ball and socket joint, and the superstructure is supported on plates located between the inner guiding and outer driving axles, allowance being made for change in distance between supports due to the action of the articulated joint on curves. Additional support is also provided by side bearers located between the two inner

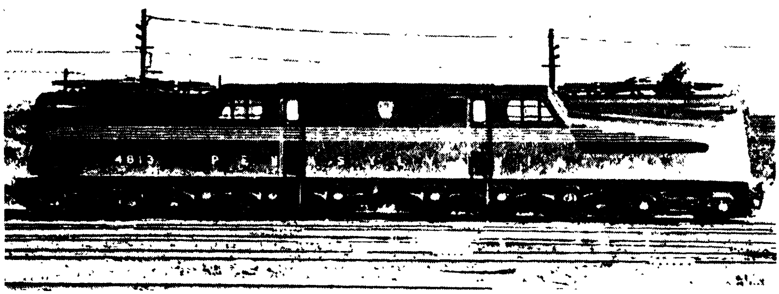


FIG. 72A. Articulated locomotive (Pennsylvania Railroad Class GG1).

driving axles on each main truck. A restraining action is applied to the running gear which, while allowing relative motion between the trucks on curves, keeps them in alignment on straight track.

Twin motors are employed, six of these machines being mounted, using three-point suspension, on the main frames, and these drive the road-axles through single reduction gearing with quill and cup flexible transmission, cup and rubbing plate equipment being installed on all driving wheels at both sides of the locomotive. Each motor is made up of two multiple-wound armatures and twelve-pole laminated stators, the latter fitted with open slots which contain the commutating, compensating and exciting field windings, all connected in series. The motor is designed to operate on 460–600 volts, i.e. 230–300 volts per armature, and weighs 14,500 lbs.

Ventilating air is taken from the cab to the motors, injected over

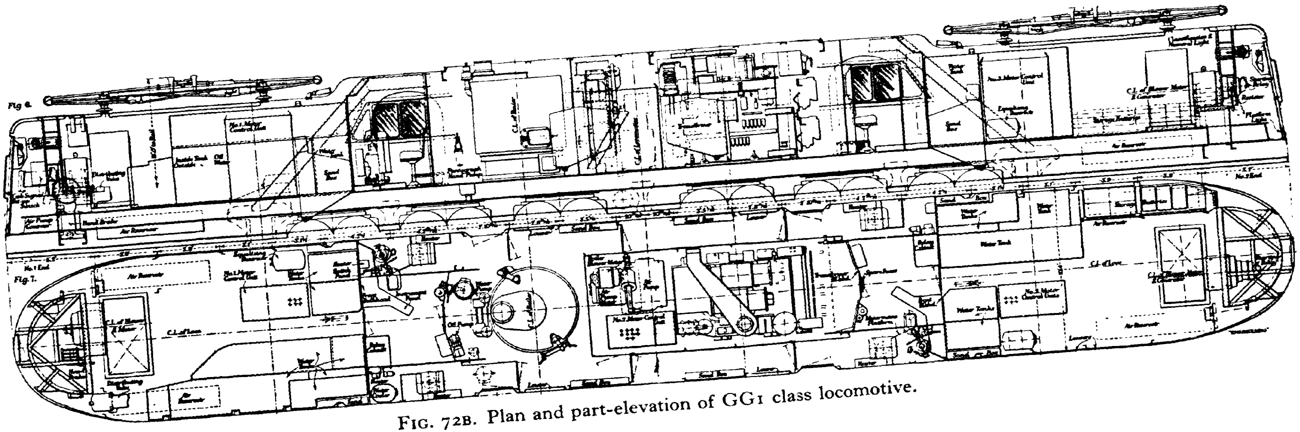


FIG. 72B. Plan and part-elevation of GG1 class locomotive.

the commutators and exhausted at the pinion ends, multiple paths for air circulation being arranged in armature and stator.

The all-welded superstructure is designed to be pleasing in appearance, and is streamlined to provide a central cab, containing the heating boiler and main transformer, etc., with a driving position for each direction of running, together with two rounded nose-compartments containing oil, air and water tanks, motor control units, batteries and motor-blower sets. One double-pan pantograph is mounted on the roof above each nose-compartment, and collects power from an 11,000 volt 25 cycle trolley-wire. A plan and part-elevation of the locomotive appears in Fig. 72B.

Control is by electro-pneumatic unit switches and preventive chokes working in combination with a series of tappings on the secondary of the main transformer, which is of the oil-immersed type. Power for the control circuits, etc., is provided by a 32 volt generator working in parallel with a battery. Full information appears in the Appendix, page 314.

U.S.A.: Mixed-Traffic Articulated Locomotives. The latest type of electric locomotive to go into service in the U.S.A. was introduced in 1943 on the New York, New Haven and Hartford Railroad, pioneers in main-line electric haulage which they introduced in 1907. Ten of these locomotives have been built and are designed to haul 5000 ton freight or 20 coach passenger

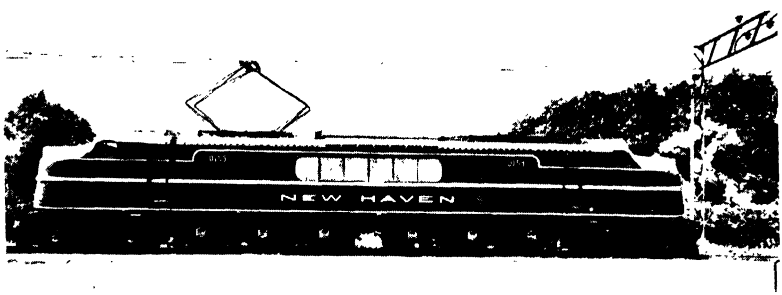


FIG. 73. 4860 h.p. mixed-traffic locomotive.

trains over the 100 mile section between New York and New Haven. Fig. 73 shows a photograph of the locomotive, and it will be seen that the running gear is very similar to the Pennsylvania $2\text{–}C_0+C_0\text{–}2$ articulated passenger locomotive just described.

A streamlined superstructure is provided and is divided up into several compartments which contain the various items of equipment. The main and auxiliary control apparatus is arranged

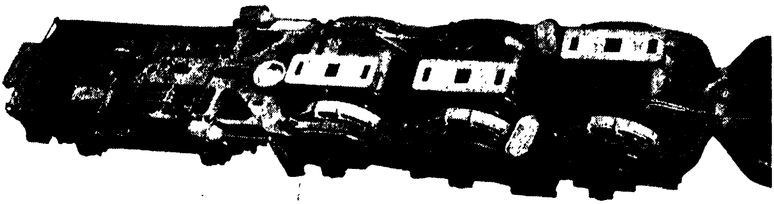


FIG. 74. One-half of running gear of 4860 h.p. articulated locomotive.

on frames which are removable in complete units through hatchways in the roof. Views of these frames are shown in Fig. 75 and many of the items, such as electro-pneumatic unit-switches,

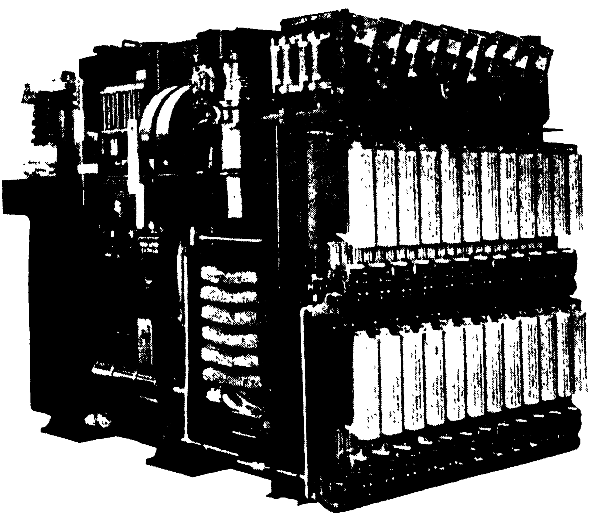


FIG. 75A. Main power control group.

auxiliary relays, main transformer, voltage regulator, can be clearly seen. Driving positions are provided near to each end of the

main body, situated behind two rounded noses which house compressors, batteries and automatic signalling equipment. Two double-pan pantographs are sunk into recesses in the roof and may be used either singly or together for collection from the

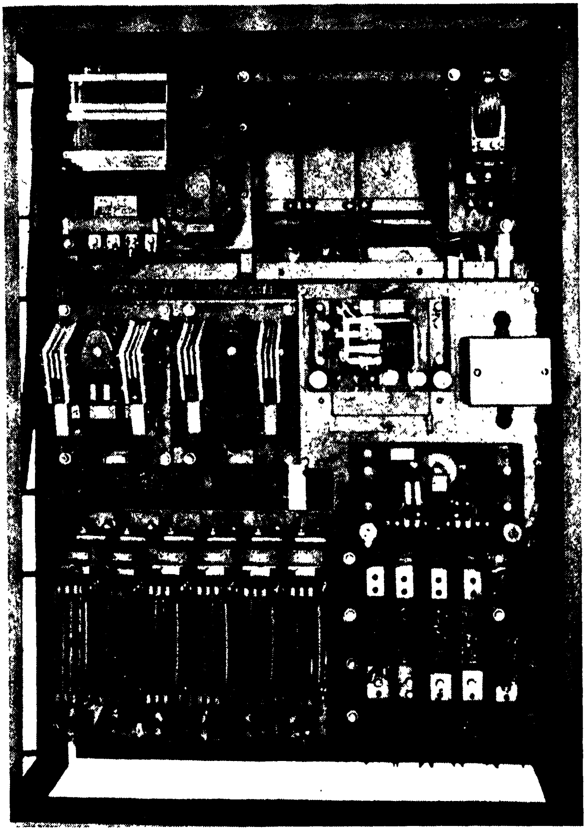


FIG. 75B. Main auxiliary control group.

11,000 volt supply. (See Appendix, page 311, for all leading dimensions and electrical information.)

Switzerland: Rigid-Framed Passenger Locomotives. Turning now to Europe, one of the most extensively electrified systems in the world is that of the Swiss Federal Railways, and in this chapter four classes of locomotive operated by this concern are dealt with. The earlier and most numerous of these loco-

motives are the 2-C_0-1 and 2-D_0-1 types illustrated in Figs. 76-77. The former, rated at 2300 h.p., was introduced in 1923 and, as a development from it, came the 3100 h.p. machine introduced in 1928, since which date the 127 locomotives in this class have come

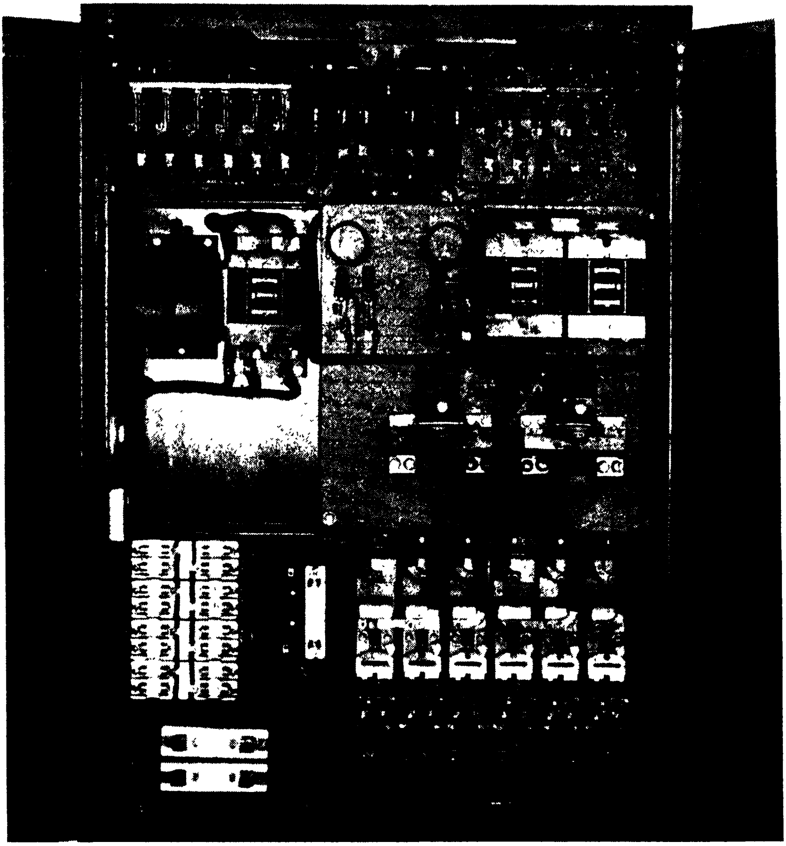


FIG. 75C. Main auxiliary control group.

to handle a large portion of the traffic on the system. As these two machines are very similar in construction and contain many standardised parts, including even identical traction motors, the description now following is confined to the latter machine.

The main frames are built up from two 28 mm. longitudinal plate sections suitably braced, in the central section of which are the four driving axles, with a pony truck and a four-wheel bogie

situated externally to provide guidance and stability whilst keeping the axle-load within limits. To allow the long rigid wheelbase of the driving axles to negotiate sharp curves without difficulty, the

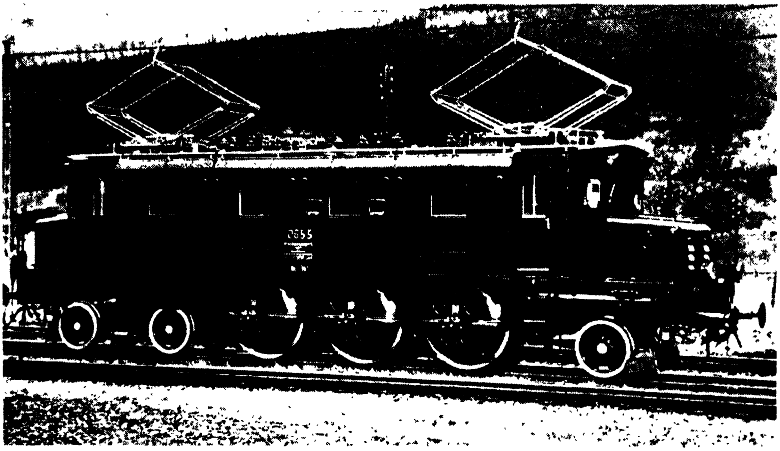


FIG. 76. 2300 h.p. Swiss Federal Railways locomotive.

two inner axles are permitted a certain amount of sideplay. Four 775 h.p. single-phase series-commutator type traction motors are mounted in the frames and the necessary flexible transmission is

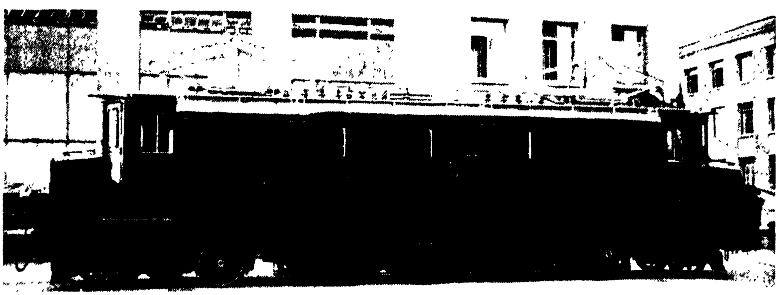


FIG. 77. 3100 h.p. Swiss Federal Railways locomotive.

provided by a series of Buchli link mechanisms, the external cases and gear-wheels of these being carried in special dish-shaped frames attached to the main longitudinal member.

At the side of the locomotive above this driving gear, a side corridor is arranged to link the driving cabs ; whilst, on the other side of the superstructure, i.e. beyond the main motors which project some distance above the frames, are mounted the blowers with their driving motors and other auxiliary machines, an arrangement chosen to counterbalance the overhung weight of the main flexible drive equipment. The main auto-transformer is situated above the four-wheel bogie and surmounted by a sliding contact

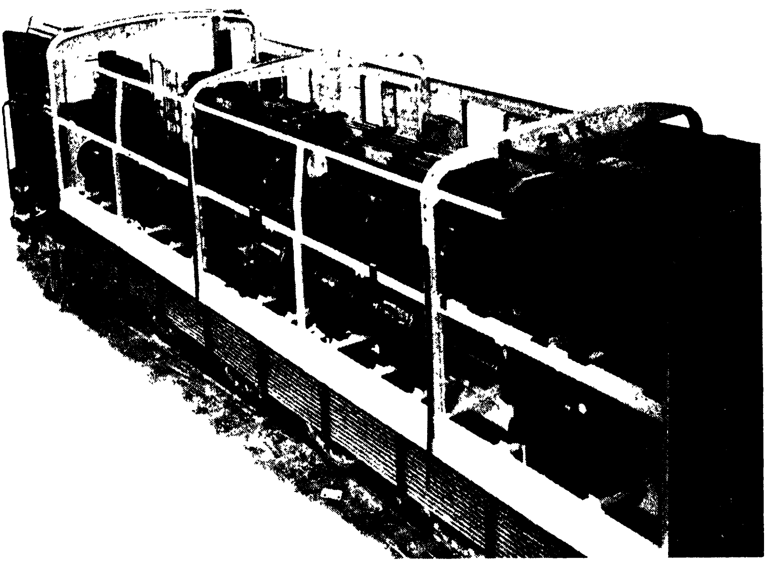


FIG. 78. Swiss Federal 2–D_0–1 locomotive with external sheeting removed.

tap-changer with its associated cam-contactors, bus-bars being employed to connect this latter with the four traction motors. Fig. 78 shows a partial side view of the locomotive with the external sheeting removed. The transformer and tap-changer are on the lower right with the motor bus-bars running lengthwise from them ; note the auxiliary machinery and the transformer oil-cooling tubes below the running plate.

The main transformer is of the oil-immersed separate-cooler type and its secondary winding has only seven tappings, but by the use of an auxiliary buck and boost transformer these are extended to provide 21 running positions (see Chapter Three,

page 68). Tap-changing is controlled by a small D.C. motor and position regulator designed to follow in sequence all movements of the main control handle, but, in cases of breakdown or emergency, can be accomplished manually by direct drive from the controller. (See Appendix, page 307, for further details.)

Switzerland: 12,000 h.p. Twin-Unit Locomotive. In 1932 two experimental locomotives of 8800 h.p. were introduced on the Swiss Federal Railways and, as a result of the data obtained from these whilst in service, a similar machine was ordered in 1937 in which it was found possible to increase the rating of the locomotive to 12,000 h.p. while effecting a slight reduction in overall weight.

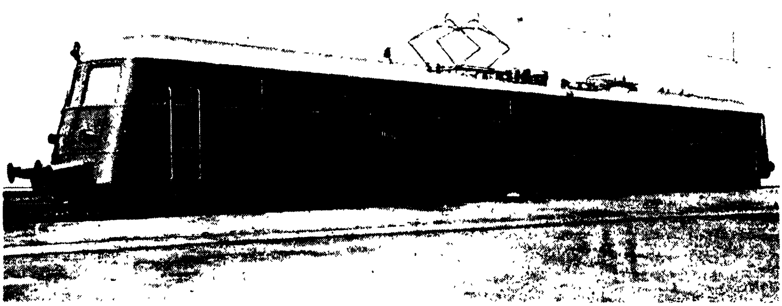


FIG. 79 (i). Swiss 12,000 h.p. twin-unit locomotive.

The locomotive, together with a plan and elevation, is illustrated in Fig. 79 and it will be seen that it comprises two close-coupled sections which are almost identical with one another. Reference may also be made to Fig. 18 which shows a cross-section of the driving-gear. The wheel arrangement of each unit is $1\text{–}B_0\text{–}1\text{–}B_0\text{–}1$, so arranged that the central carrying axle and the two adjacent driving axles are rigidly mounted in the main frame, whilst the outer driving and carrying axles make up a two-axle bogie, a system introduced on several locomotives built by the Swiss Locomotive and Machine Works, which proves very effective for both flexibility and guiding purposes. In order to obtain a very high tractive effort at starting, a compressed air weight-shifter is employed to transfer weight from the central carrying axle to the driving axle when required, so increasing the available adhesive weight.

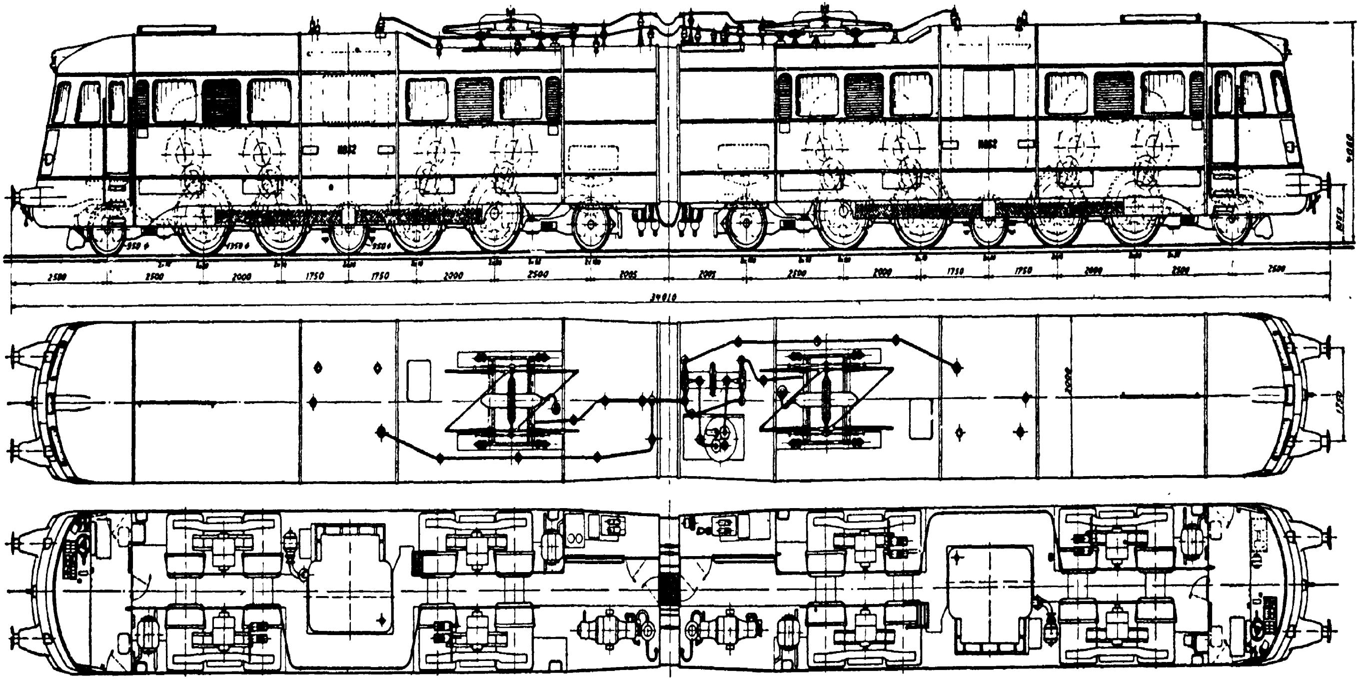


FIG. 79 (ii). Swiss 12,000 h.p. twin-unit locomotive.

A total of sixteen traction motors, eight per unit, are installed, and individual axle drives of the Winterthur universal pattern transmit the torque from the armatures to the road axles through a double reduction flexible gear. Two motors, mounted in line transversally, provide the tractive power for each axle and permit the use of a central gangway passing between the motors at their commutator ends, an arrangement which makes the brushgear, etc., extremely accessible. Four motor-blower groups supply

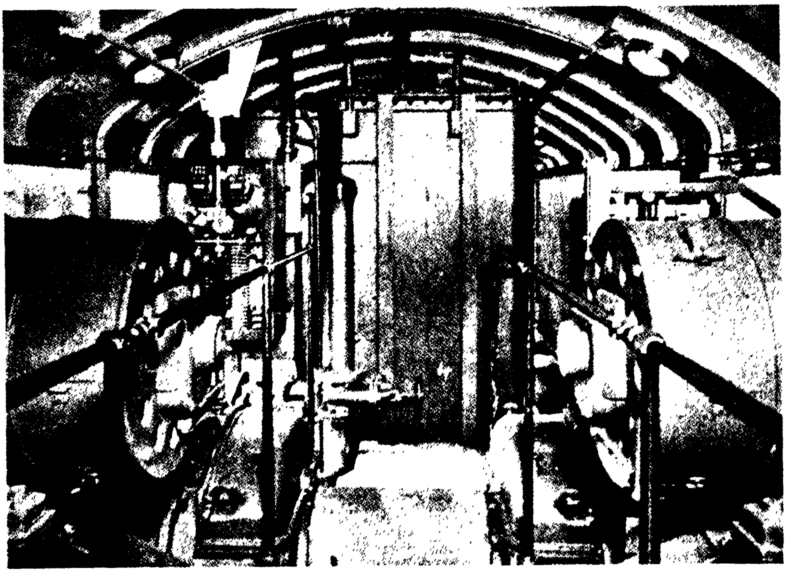


FIG. 80. Interior of motor compartment—Swiss 12,000 h.p. locomotive.

cooling air in each unit and are mounted one above each pair of longitudinally adjacent machines. Fig. 80 shows the interior of the locomotive with main traction motors, motor blowers and central gangway leading to the transformer compartment in the centre of the main superstructure, the most suitable position for the transformer due to the weight involved. Flanking this compartment are the two main-motor chambers and at the outer ends of the complete locomotive two driving positions are installed.

The two pantographs, situated one at the inner end of each unit, are linked by H.T. bus-bars with a flexible jumper and collect power at 15,000 volts $16\frac{2}{3}$ cycles from the trolley-wire. High-

tension tap-changing control is utilised, a full description of the apparatus and circuits appears on pages 72–77, together with illustrations. A maximum tractive effort of 140,000 lbs. can be maintained up to 38 m.p.h., beyond which point this decreases steadily to 34,000 lbs. at the maximum speed of 68 m.p.h.

Switzerland; 6000 h.p. Multiple-Unit Locomotive. As a result of exhaustive tests on the operation of the 12,000 h.p. locomotive just described, it was decided to divide the two close-coupled units for future construction and arrange these as 6000 h.p. locomotives with provision for multiple-unit operation.

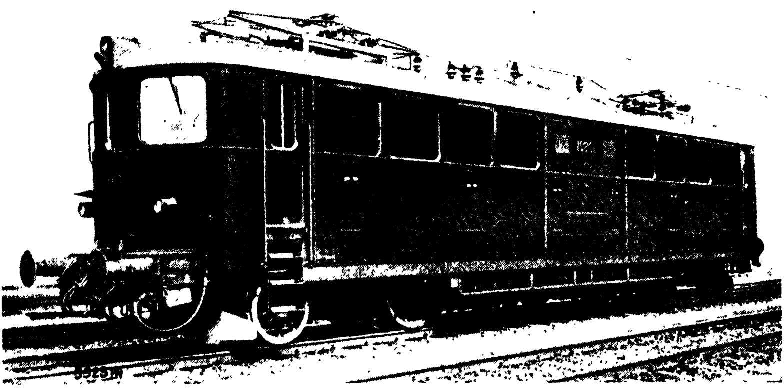


FIG. 81. Swiss Federal Railways 6000 h.p. $1\text{–}D_0\text{–}1$ locomotive.

Several of these new machines are now in service; the prototype is shown in Fig. 81 with a plan and elevation in Fig. 82 (i), from which it will be apparent that it was possible to eliminate the central carrying axle and so make the wheel arrangement $1\text{–}D_0\text{–}1$. The SLM-type bogie is still applied and comprises the carrying and outer driving axles at each end of the running gear, the arrangement of which is shown in Fig. 82 (ii), the two central axles only being rigid. When operating in pairs, these new locomotives are capable of hauling a 750 ton train up a 1 in 38 gradient at 40 m.p.h., so making for rapid handling of the heavy international expresses on the St. Gotthard line through the Alps.

Details of both 12,000 and 6000 h.p. machines are given in the Appendix, pages 307 and 308.

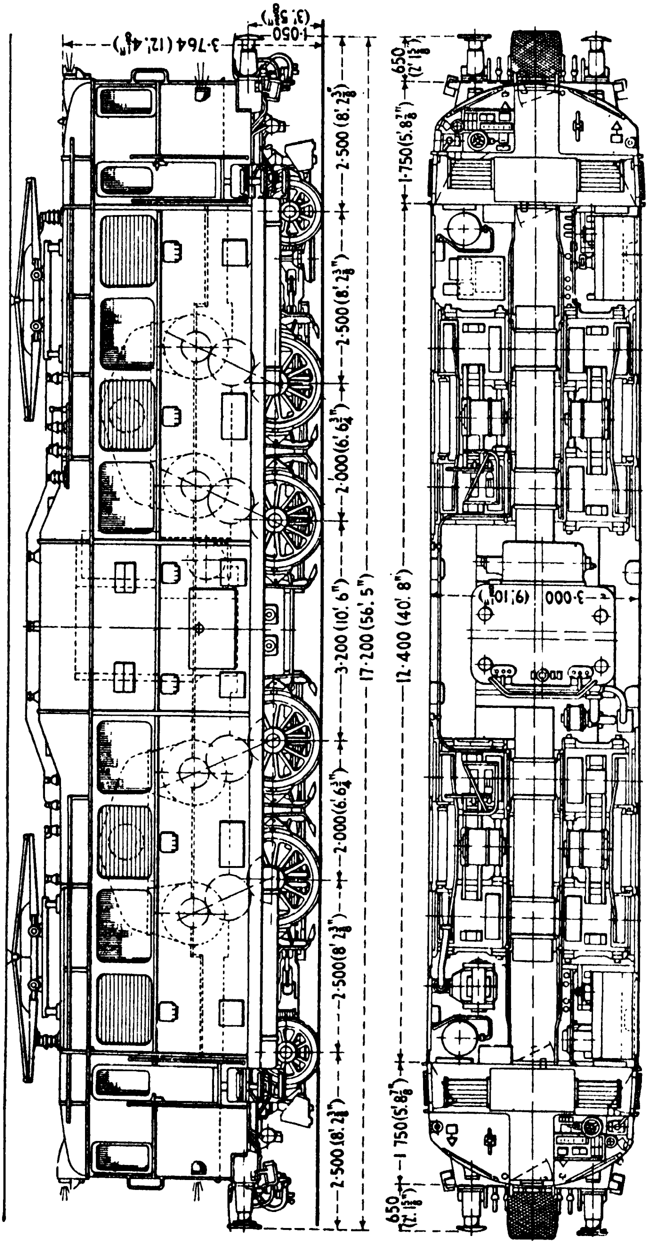


FIG. 82 (i) Plan and elevation of $1\text{-}D_0\text{-}1$ locomotive—Swiss Federal Railways—note the special combination bogie.

Switzerland: Articulated Mixed-Traffic Locomotive. In 1939 the Berne–Loetschberg–Simplon Railway introduced two new 6000 h.p. articulated locomotives, details of which appear in

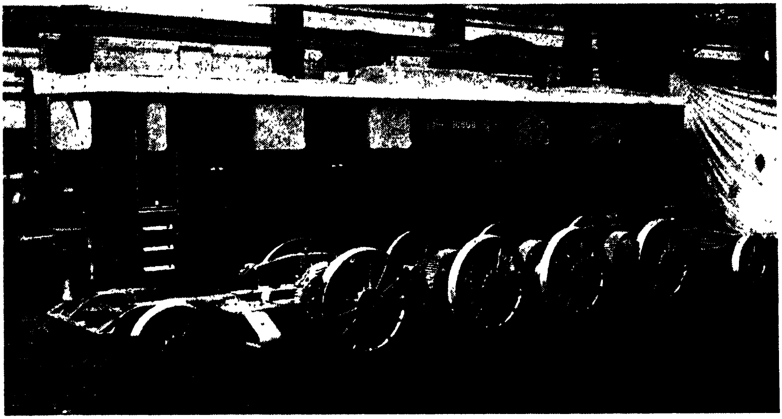


FIG. 82 (ii). Running gear of $1\text{--}D_0\text{--}1$ locomotive—Swiss Federal Railways—note the special combination bogie.

Fig. 83. The general assembly comprises two large articulated main trucks on which is mounted the superstructure, each main

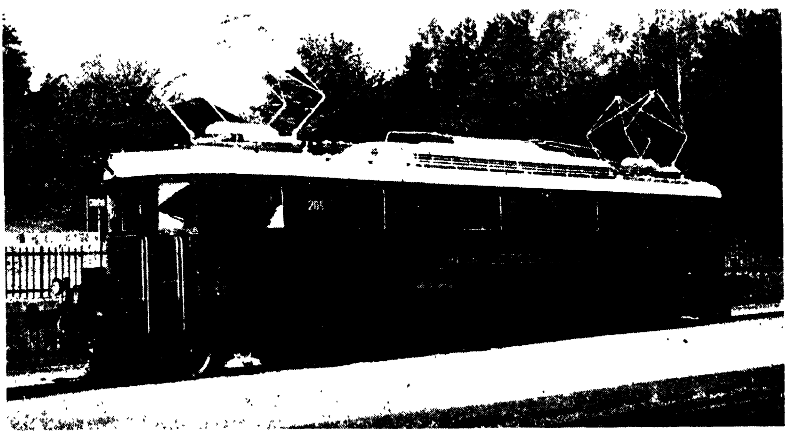


FIG. 83 (i). Swiss 6000 h.p. articulated locomotive.

truck having three driving axles and one pony carrying axle, all running in roller bearings. Each axle is driven by a flexible

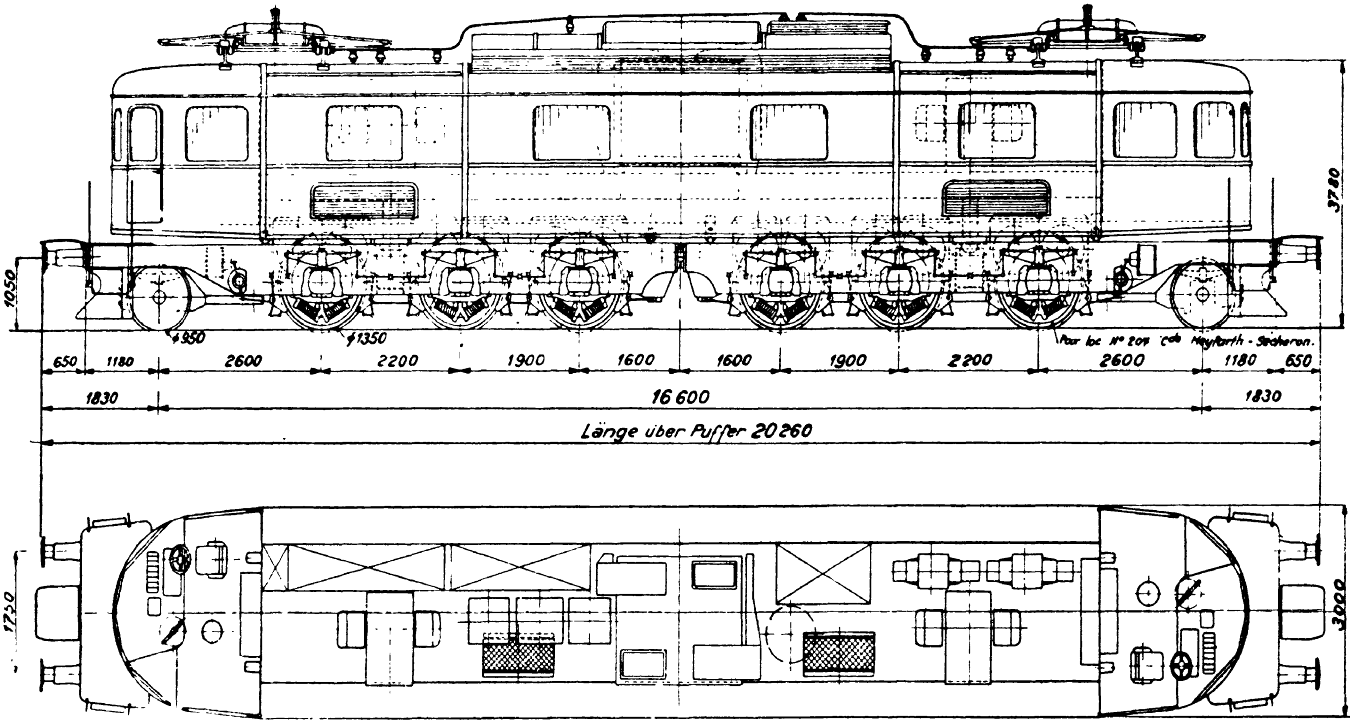


Fig. 83 (ii) Swiss 6000 h.p. articulated locomotive.

spring and quill drive of Sécheron design from a series-compensated shunted-commutating-pole twin-armature traction motor (Fig. 13), which is mounted on the truck just above the axle and supports the hollow quill-shaft in bearings beneath its frame. The adoption of the twin-armature principle enables a motor rated at 1000 h.p. to be split up and accommodated low in the frames (Fig. 84), instead of occupying a considerable proportion of the available space in the superstructure, as in the Swiss Federal 1–D_0–1 6000 h.p. locomotive. In common with normal Sécheron practice in recent years, an equalising system is in-

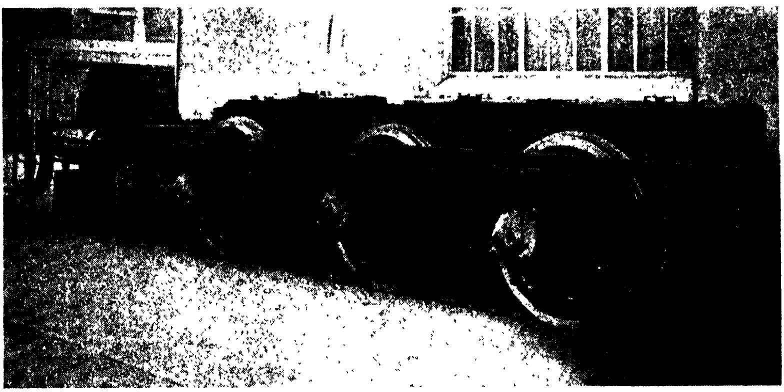


FIG. 84. Main truck of 6000 h.p. locomotive.

corporated in the truck design to minimise weight transfer from loading to trailing axle when hauling heavy loads.

The superstructure is of moderately lightweight construction, as no tractive force is transmitted through the frames, the largest item of equipment mounted therein being the main transformer situated in the centre. A member of section, reinforced by cross-braces, runs the length of the locomotive and is supported on two pivots situated between Nos. 1 and 2, 5 and 6 driving axles, one pivot being permitted a small amount of play in a longitudinal direction to allow for relative movement between the trucks at the articulated joint. Further supports for the superstructure are provided between the carrying and outer driving axles and beneath the transformer adjacent to the articulated joint, these bearings making possible the correct division of weight between the various axles besides assisting in the minimising of weight transfer.

The general disposition of the electrical equipment is shown in the plan, the twin side-corridor layout being adopted. As mentioned earlier, the main transformer is centrally situated, and

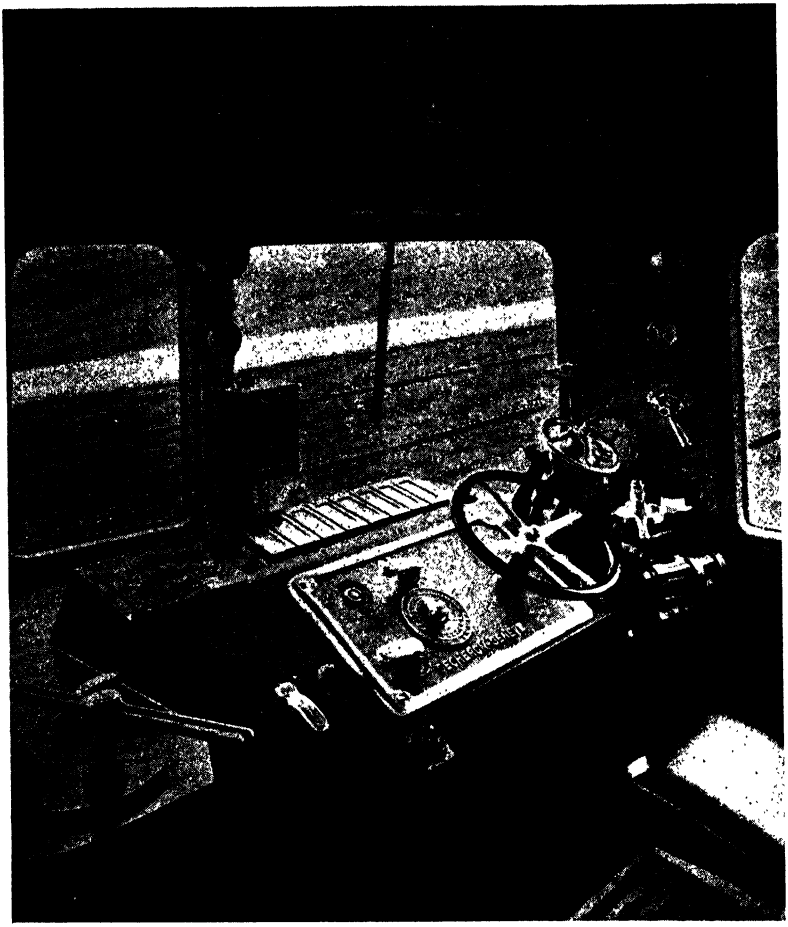


FIG. 85. Driving cab of articulated locomotive.

is cooled by forced oil circulation through a radiator with side louvres projecting from the roof between the pantographs. Mechano-pneumatic contactor control, employing 24 contactors, operates in conjunction with twelve tappings on the secondary of the transformer and with three preventive chokes to give 24

running notches in both power and braking connection, the contactors being closed singly and in groups of up to four. A rheostatic braking system is installed, in which each pair of armatures is connected to a separate resistance and all the motor fields, connected in series, are separately excited from the main transformer secondary. When operating on power, the six twin-motors, each with its associated field windings, are all connected in parallel.

Train heating is provided, when required, by tappings of 800 and 1000 volts on the main transformer, the supply from which is

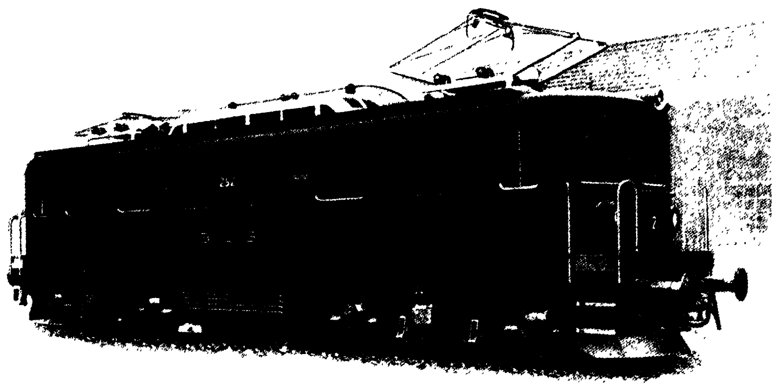


FIG. 86 (i). B.L.S. 4000 h.p. B_0–B_0 locomotive.

passed through sockets and jumpers to heaters throughout the train.

A pleasing semi-streamlined appearance has been provided, and incorporates an excellent view of the track ahead from each driving cab, this being arranged to accommodate both driver and assistant comfortably and in the best possible position for control of the locomotive. Full statistical details appear in the Appendix, page 305.

Switzerland : Double-Bogie Passenger Locomotive. Two new 4000 h.p. express passenger locomotives were introduced by the Berne–Loetschberg–Simplon (B.L.S.) system in 1945, which, in contrast to standard Swiss practice, are of lightweight construction, weighing only 78½ tons and employing two four-wheeled bogies with traction motors mounted thereon. In service, these

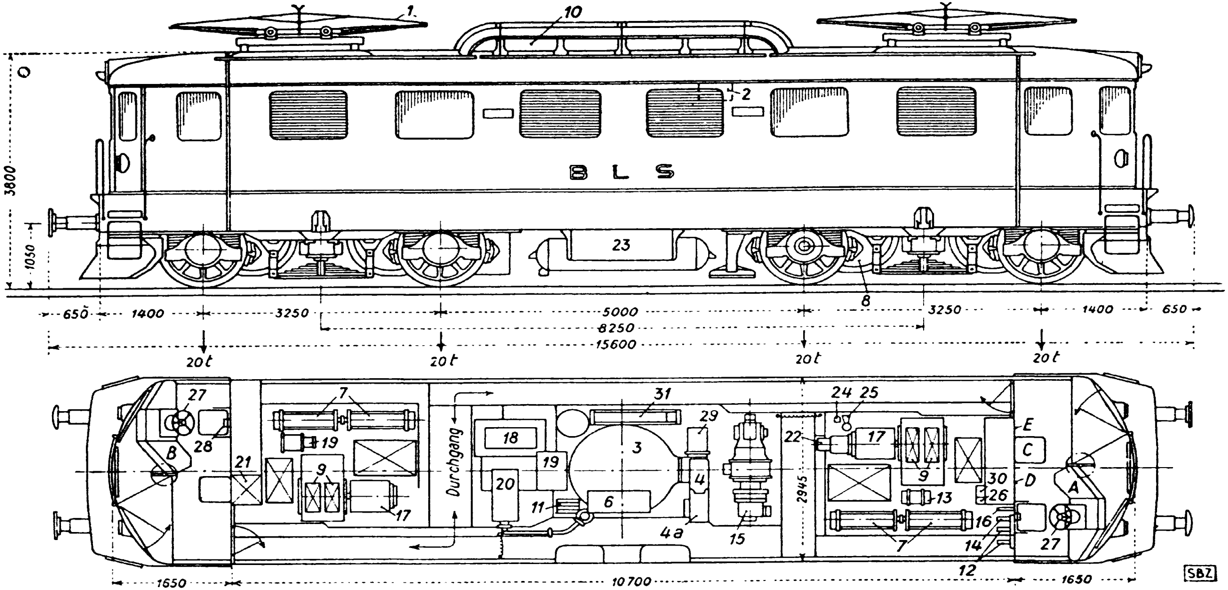


FIG. 86 (ii). B.L.S. 4000 h.p. B_0–B_0 locomotive.

A.
B. } Driving positions.
C. A.C. switchboard.
D. D.C. switchboard.
E. Relay panel.
1. Pantograph.
2. Pneumatic circuit-breaker.
3. H.T. Transformer.
4. Tap-changer.
6. Overload limit resistance.
7. Change-over switchgear.
8. Traction motor.
9. Inductive shunts.
10. Brake resistance.
11. 4-pole contactor.
12. Heating contactors.
13. Boosting transformer.
14. Compressor motor contactor.
15. Compressor.
16. Blower motor contactor.
17. Traction-motor-blower motor.
18. Blower-motor starting resistances.
19. Lighting generator.
20. Transformer blower and oil pump.
21. Oil pre-heater.
22. Braking exciter.
23. Battery 36v. 100 Ah.
24. E.P. pantograph control.
25. Hand air-pump.
26. Main circuit-breaker closing relay.
27. Master controller.
28. Hand-drive for tap-changer.
29. Tap-changer motor.
30. Overspeed and braking relays.
31. E.P. contactor groups.

locomotives are capable of hauling a 390 ton train at 47 m.p.h. up a gradient of 1 in 40, and a 630 ton train at 56 m.p.h. up a gradient of 1 in 100.

Both bogies and superstructure are of all-welded construction. Light alloys have been used extensively in the locomotive body. Equalising arrangements are incorporated in the design of the running gear to prevent oscillation on straight track and ensure the smooth negotiation of curves. Each bogie carries two 1000 h.p. traction motors, which drive the road-axles through a new spring-disc arrangement introduced by Messrs. Brown-Boveri. The lay-out of the superstructure and its general appearance are in many

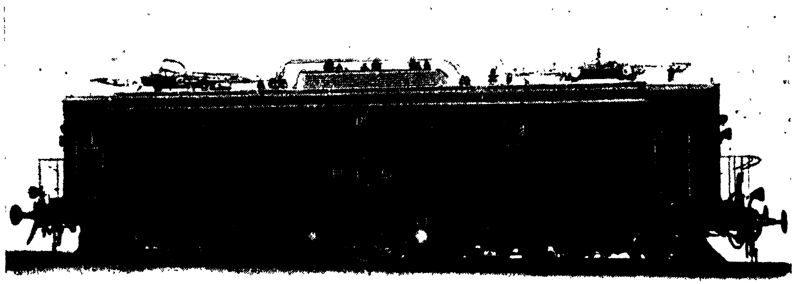


FIG. 87. 1–E–1 3000 h.p. locomotive.

ways similar to the $1\text{–}C_0 + C_0\text{–}1$ locomotives of the same company, but in these latest machines a lightweight high-tension tap-changer has been adopted in which 28 operating positions are provided.

A view of the locomotive appears in Fig. 86; statistics page 305.

Switzerland: Freight and Shunting Locomotives. Fig. 87 shows a rebuilt freight and mixed-traffic locomotive of the B.L.S. system. Originally constructed in 1913 as a two-motor 2500 h.p. machine, it was decided to modify this in 1941 and, as a result, the locomotive has now re-appeared with four motors, whose ratings total 3000 h.p., which provide a maximum speed of 55 m.p.h. The collective drive of the Scotch Yoke type is still

retained, each pair of motors driving one jackshaft and the two jackshafts driving the five coupled axles through the frame, an unusual arrangement for such high speeds of operation.

Figs. 88, 89 show typical shunting locomotives.

The first is a standard gauge three-axle machine of the B.L.S. system, weighing 39 tons in working order. One 615 h.p. forced-ventilated traction motor is mounted on the main frames, and torque from its armature shaft is transmitted to the driving wheels

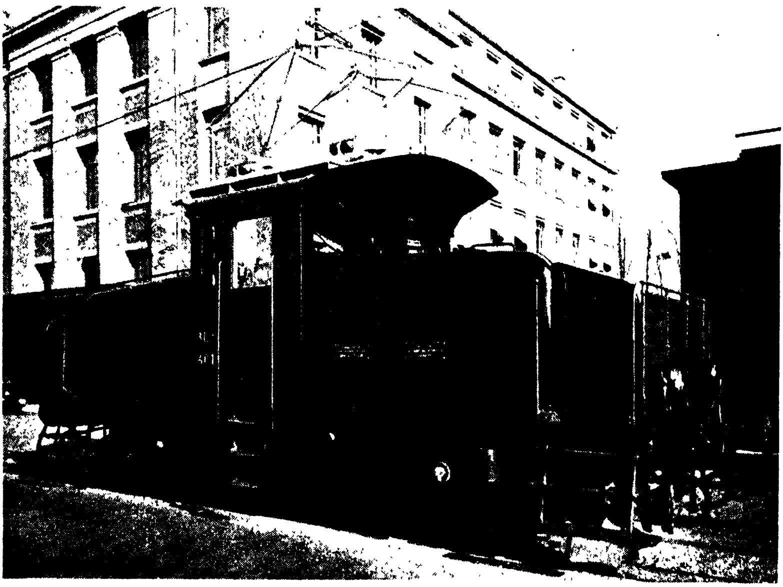


FIG. 88. Typical Swiss shunting locomotive.

by a geared jackshaft with connecting rods, all six wheels being coupled together. The driving compartment is situated centrally above the main frame, where the driver is afforded an excellent field of vision in each direction, and the electrical equipment is divided up between the two hooded sections flanking the cab, one containing the traction motor, blower, etc.; the other, the main transformer with a series of electro-pneumatic contactors for acceleration and speed regulating purposes. A pantograph for current collection is mounted on a false roof above the cab and carried on insulators, power being collected at 15,000 volts $16\frac{2}{3}$ cycles. Note the gangways situated between each hood and

buffer beam, which allow the shunter to ride on or cross from one side to the other of the locomotive.

The second illustration shows a metre-gauge 315 h.p. locomotive of the Rhaetian Railway system which, though technically a rebuild, is more a replacement introduced in 1941. It is designed to operate from either an 11,000 volt 16⅔ cycle trolley-wire supply, or from a large storage battery carried on the locomotive, which is charged by means of a small convertor set. The wheel arrangement is 1–B–1, with two driving axles to which power is transmitted by a double-reduction-geared jackshaft-

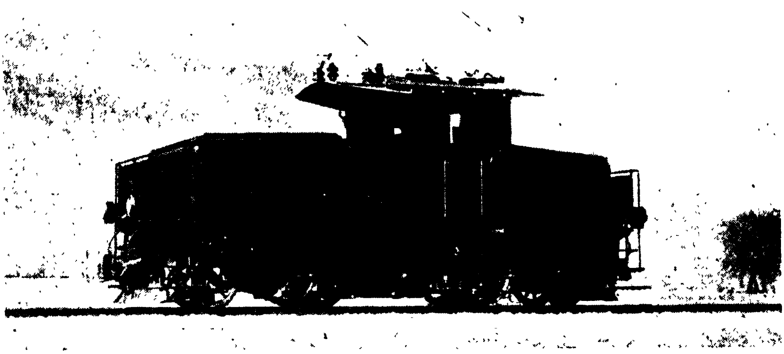


FIG. 89. Rhaetian Railways narrow gauge shunting locomotive.

siderod drive from a traction motor mounted above the frames. The central driving cab is flanked by two equipment compartments covered by removable hoods, the smaller compartment containing the battery and the larger, the traction motor, transformer, motor-blower and motor-generator sets, vacuum pump, etc. Two desks are fitted in the driving cab, one at each side of a central cross gangway, and these contain the controller, auxiliary control gear and similar items.

Sweden: 1975 h.p. General Purpose Locomotive. When the Swedish State Railways electrified the main Stockholm–Göteburg line, a route of approximately 290 miles, in 1926, a standard electric locomotive was designed which could be adapted for either passenger or freight workings by the installation of one of

two differing gear ratios. As the electrified system has gone further afield, the number of such locomotives has steadily increased until, at the present day, about 300 are in service, and it is only in recent years that it has been decided to supersede this type on certain duties by a more powerful locomotive, experiments to find an ideal design for which are outlined later.

This standard locomotive has a 1–C–1 wheel arrangement, the driving torque being transmitted from the traction motors by a collective drive of the jackshaft-siderod type. Two 30 mm. side-plates suitably braced make up the main side-frames, and carry the axle-boxes for the three driving axles, together with the forced lubricated jackshaft bearings. Further support for the frame is provided at its outer ends by two single-axle Bissel trucks. The superstructure is built up of wood planking attached to a strong steel framework, the roof, which is covered with roofing canvas, having a series of hatches to facilitate removal of the various items of equipment, and providing support for the two lightweight pantographs.

The tractive power is developed by two 987 h.p. A.C. traction motors and transmitted to the jackshaft by twin gears of the single helical pattern, a spring coupling being incorporated between the armature shafts and each pinion. The motors are not built as entirely separate units, but their various parts are mounted on the locomotive frame, which, for this purpose, is furnished with upper and lower housings to carry the stators, brush rockers and bearings, the upper housing being designed to support, in addition, a pair of blower-fans with a common driving motor. The general arrangement of the apparatus is apparent from the plan, etc. (Fig. 90B).

A.S.E.A. electro-magnetic contactor control, as outlined on pages 68–71 and shown in Fig. 39, is employed, the locomotives being arranged for multiple unit control when operating in pairs. Further details are given in the Appendix, page 303.

Sweden: Experimental "Class F" Locomotives. When it was decided that a more powerful locomotive than that just described was required, the Swedish State Railways set up a special locomotive committee to make recommendations for experimental machines and, after a considerable investigation into the many types of locomotive in service in other countries, it was

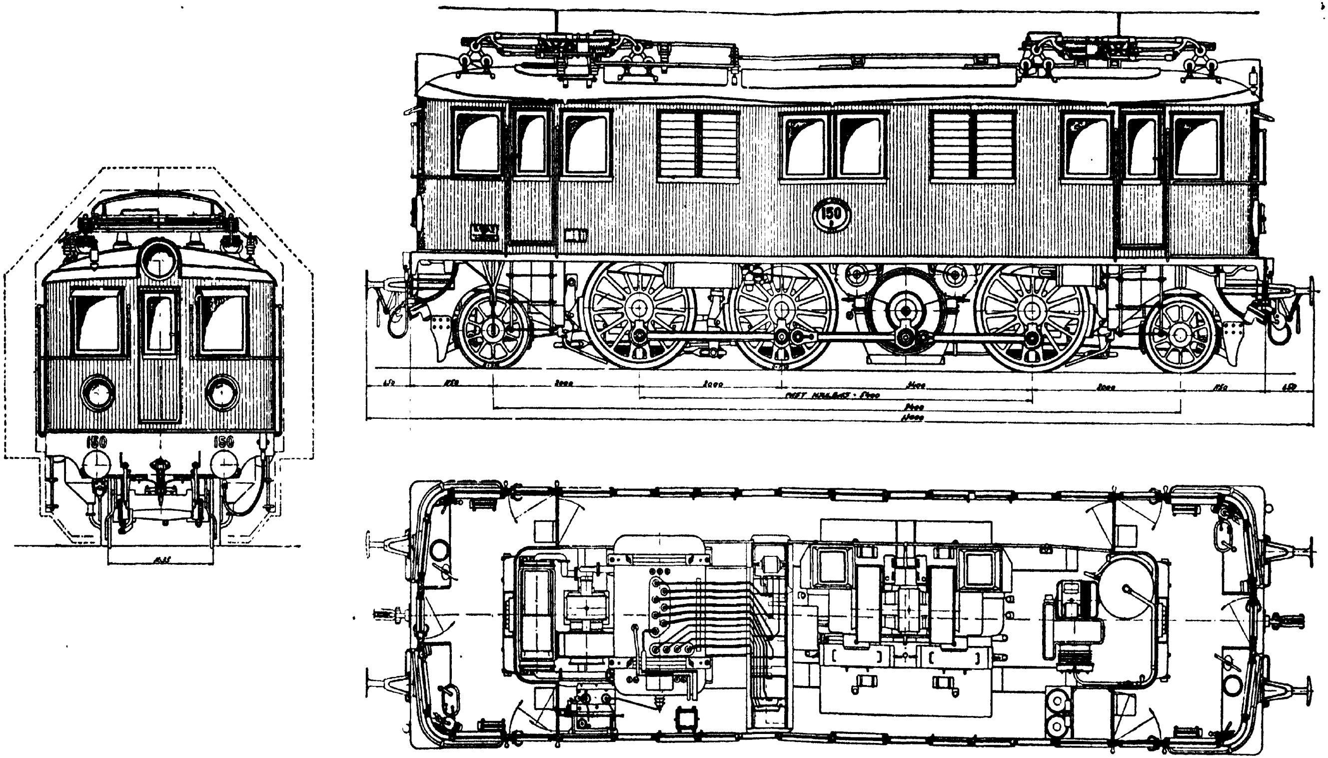


FIG. 90B. 1975 h.p. 1–C–1 Swedish locomotive.

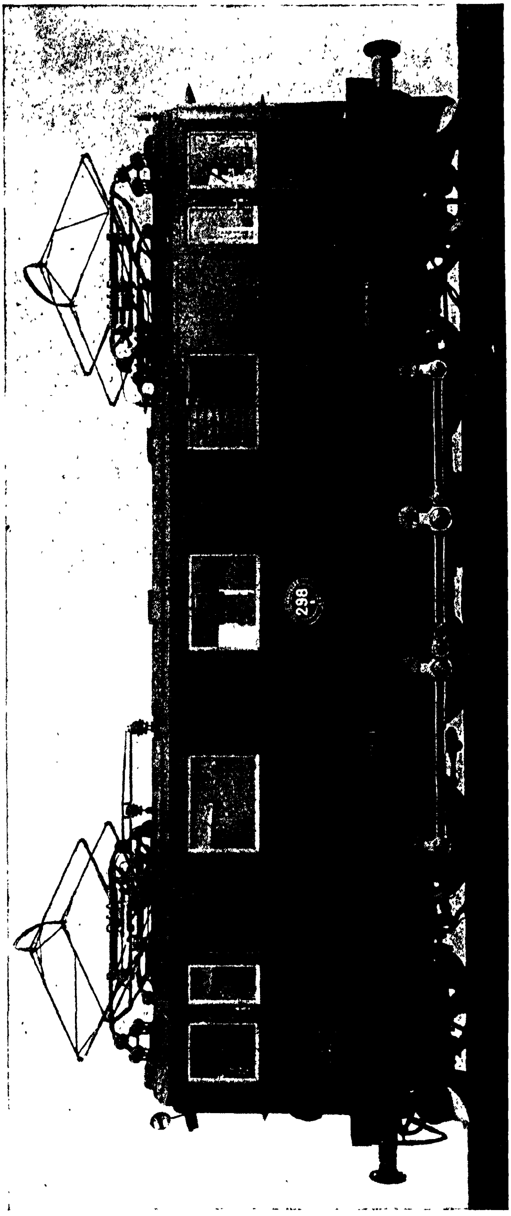


FIG. 90A. 1975 h.p. 1-C-1 Swedish locomotive.

decided to construct three locomotives which, while generally similar, would incorporate detailed differences in design for investigation into their merits. The general performance requirements were that the locomotive should be capable of hauling a 590 ton train at a maximum speed of 84 m.p.h. on level track, of handling the same load up a gradient of 1 in 100 and a load of 470 tons on a gradient of 1 in 63. These latter conditions required the developing of 3500 h.p. at 59 m.p.h. and of a maximum tractive effort of 38,000 lbs., this with an axle load limited to 17 tons.

The main frame structure is fabricated and comprises two plate frames, 25 mm. in thickness, suitably braced by stretchers, the whole supporting a semi-streamlined structure built up of welded steel sheet, with a spacious driving compartment at each end. Four driving and two carrying axles support the frame, the loading of 17 tons on the former and 16–17 tons on the latter being carried by two-point suspension on locomotives Nos. 601 and 603 and by three-point suspension on No. 602. A driving wheel diameter of 60 inches is adopted, the committee deciding in favour of retaining this size, which is standard on the 1–C–1 locomotives, due to the reduced heat on braking and the lower bearing speeds obtained. In order to accommodate the transformer, an increased spacing was necessary between the inner driving axles, and to ensure smooth riding on curves the guiding axles are spaced a distance of nine feet from the outer driving axles. Locomotives Nos. 601 and 602 have the Krauss type of combination bogie embracing the guiding and outer driving axles at each end, the former having the bogies recentralised by inclined planes and the latter by compression springs. An additional restoring force is employed on the rear bogie according to the direction of travel, a feature which assists in reducing oscillation at high speed and which is brought into operation automatically by the position of the reverser. Locomotive No. 603 has spring-centralised Bissel trucks.

Four traction motors, each of 875 h.p., are installed in each locomotive and the individual axle drives adopted have twin-gear driven quill shafts situated beneath the motors on all three locomotives. The method of torque transmission from the quills to the driving wheels differs ; it is of the Sécheron spring type in No. 601, the A.E.G. spring cup in No. 602 and an experimental A.S.E.A. spring drive in No. 603.

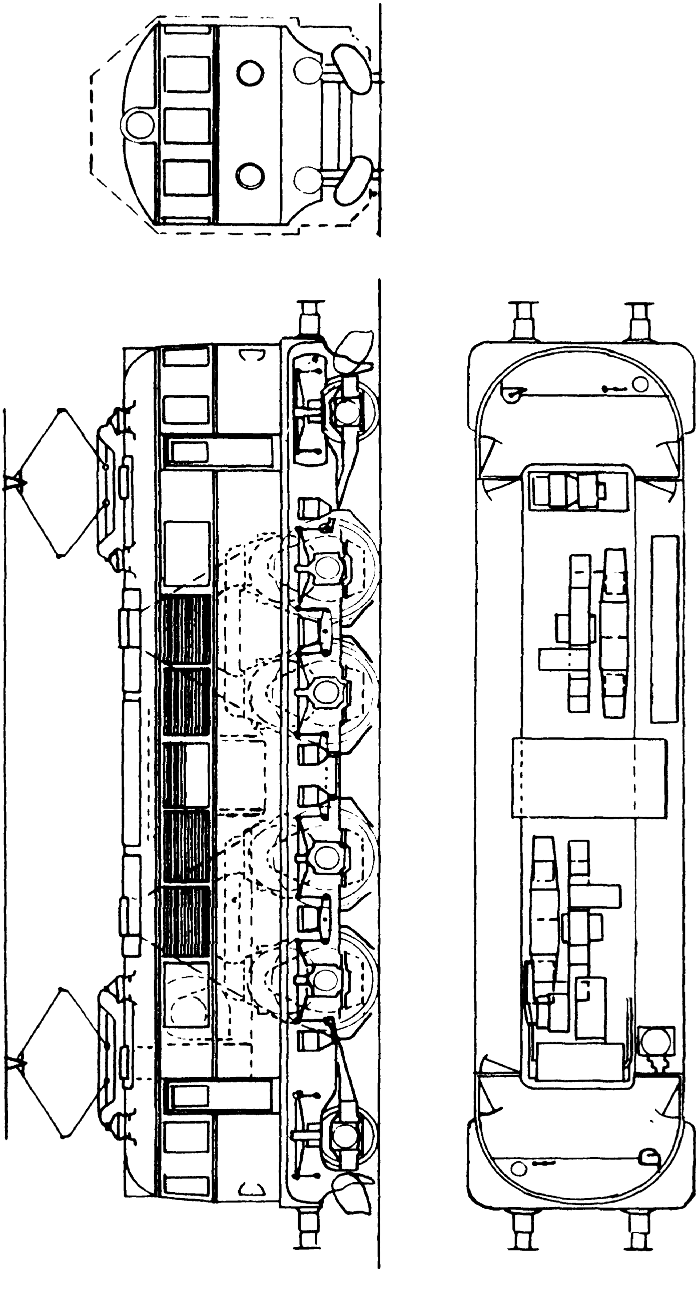


FIG. 91. Swedish 1-D_0-1 experimental locomotive (plan-elevation).

The diagram (Fig. 91) shows the general arrangement of equipment and it will be seen that the transformer is situated in the centre of the superstructure with its associated control gear in adjacent cubicles. There are two motor compartments, each containing two main traction motors and a motor-blower set which is arranged to provide separate streams of air for ventilating the stators and armatures. Other auxiliary apparatus such as the compressor, auxiliary control gear, transformer-blower, etc., is located at the outer ends of the motor compartments adjacent to the driving cabs, which are linked by two side corridors to provide maximum accessibility to all the equipment.

Main details of the electrical equipment are given in the tables, page 304, but a brief note of the diverse items tested will be of interest. Both high-tension and low-tension tap-changing systems have been tested and results have shown the former to be definitely superior; it will be installed on all future locomotives. Finely graduated control with 62 notches (on No. 602) was found to be unnecessary, the locomotive with 28 steps being quite satisfactory. Comparative installations of A.C. and D.C. for the low-voltage control circuits have demonstrated the superiority of the latter.

For a complete description of the experiments carried out on the running gear with detailed analysis of the results the reader is referred to the paper by H. G. McClean, Esq., published in the *Journal of the Institution of Locomotive Engineers*, dated Sept.–Oct., 1945.

Germany: The E18 and E19 Classes of 1–D_0–1 Locomotive. The E18 class of locomotive was introduced in 1933 on the German State Railways and in many ways is the prototype from which the Swedish experimental locomotives have sprung. It is designed for a service maximum of 90 m.p.h. and has on test attained a speed of 105 m.p.h. Two guiding and four driving axles, incorporating Krauss bogies with reverser-interlocked increased restoring forces on the trailing bogie, support a semi-streamlined frame and superstructure. Four traction motors, with a total rating of 4150 h.p., are installed and the drive is transmitted through an individual axle quill and cup mechanism.

The E19 class was introduced late in 1939, two experimental locomotives only being constructed. Generally similar to the E18 class, these were, however, geared for a service speed of 115 m.p.h.

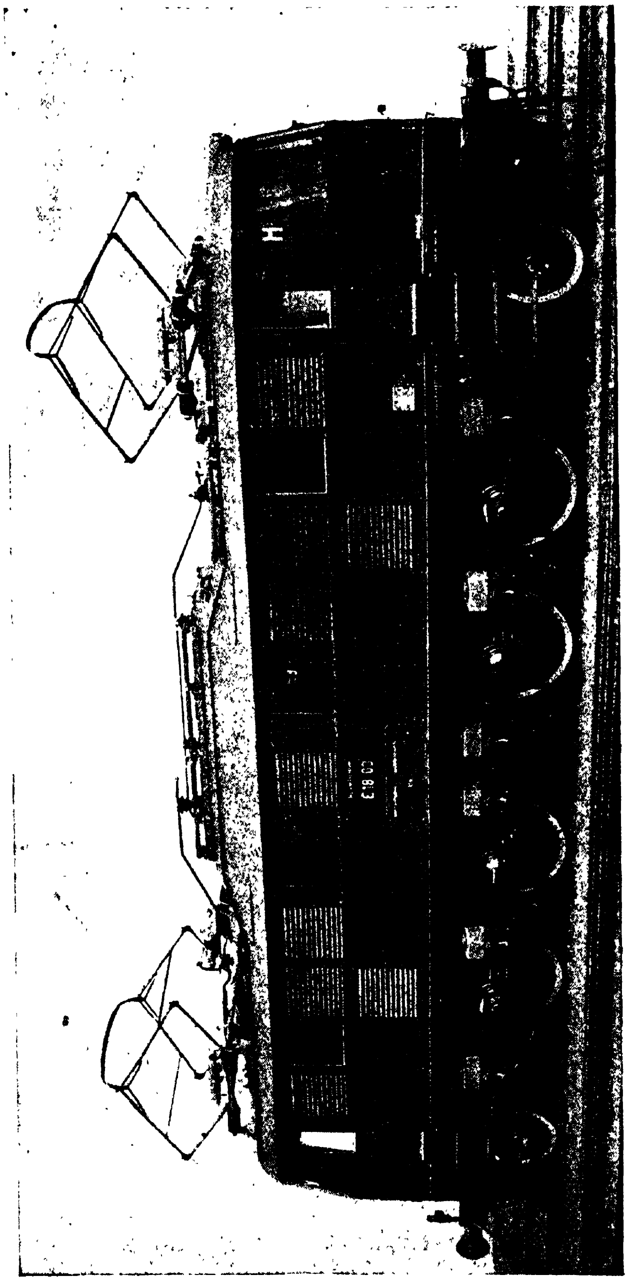


Fig. 92. E18 Class locomotive—German State Railways.

and are rumoured to have attained speeds much in excess of this value. Further details are available in the Appendix, page 297.

Italy: Typical Three-Phase Locomotives. Figs. 93, 94 show two typical three-phase locomotives of the Italian State Railways, a 1–D–1 four-coupled-axle passenger locomotive and the latest five-axle freight locomotive both with Bianchi link drive. Both were built in the 1925–1930 era.

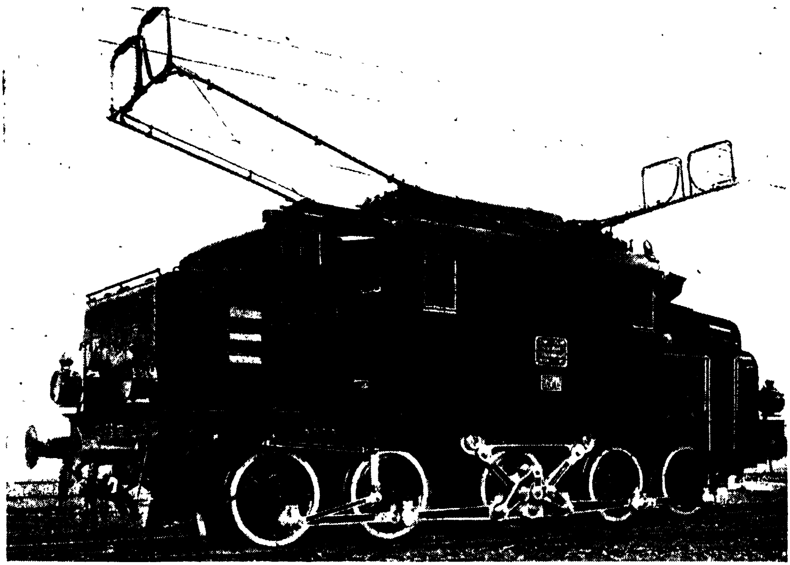


FIG. 93A. Italian three-phase freight locomotive.

The freight locomotive is a very compact piece of equipment as with an overall length of 35 ft. 4 ins. and a weight of 78 tons, it can develop continuous tractive efforts of 26,500 lbs. at 15·5 m.p.h. and 28,700 lbs. at 31 m.p.h., these being the two operating speeds obtainable. Power is supplied at 3300–3700 volts 3 phase $16\frac{2}{3}$ cycles, two separately-insulated reversible bows being carried on each main trolley boom to make contact with the two overhead wires, the third phase being earthed. The general layout of the locomotive can be seen from Fig. 93B. The central cab contains the main traction motors, main blower fan, auxiliary equipment and has two driving positions. Adjacent to this cab at each end

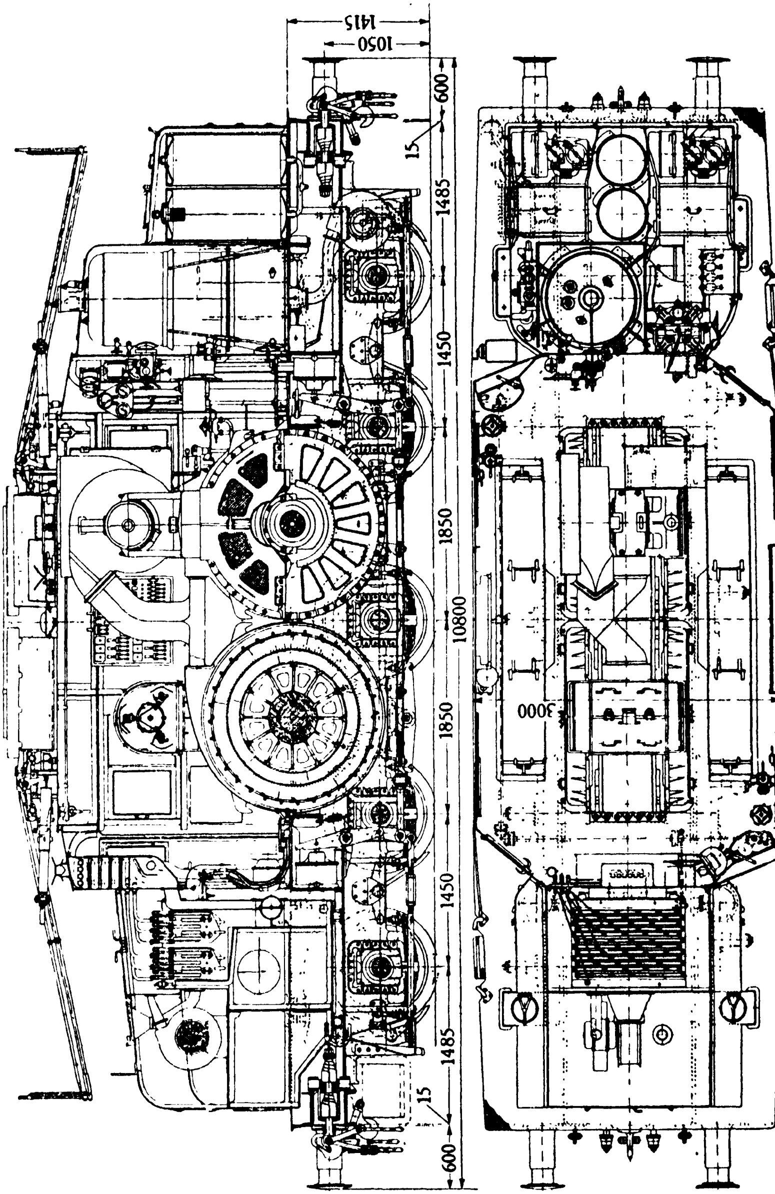


FIG. 93B. Plan and elevation of 3-phase freight locomotive. (Brown-Boveri Review.)

are two hooded compartments, one containing a naphtha-fired heating boiler with fuel and water tanks, and the other, the liquid resistances, electrolyte tank, etc.

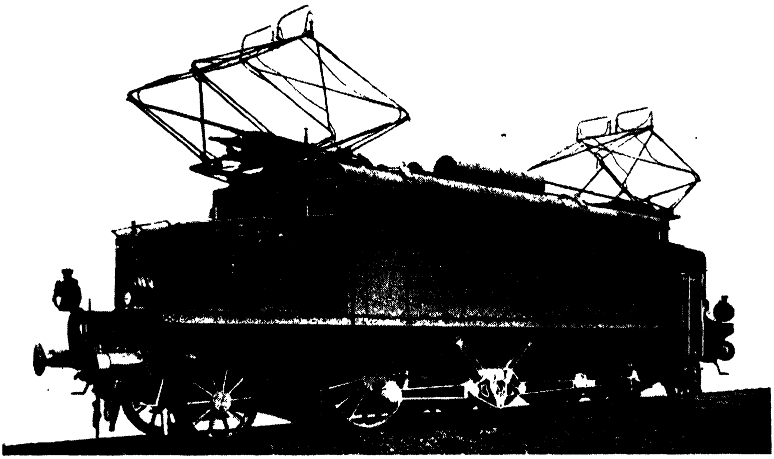


FIG. 94. 3-phase express passenger locomotive.

CHAPTER SEVEN

CONVERTOR LOCOMOTIVES

THIS general heading has been chosen to cover the various systems of locomotive control where the trolley-wire supply is changed in character or number of phases before it is passed to the traction motors. Three main examples have been selected and in each case a description of the control system and details of the locomotive itself are given. These are: (*a*) The motor-generator locomotive; (*b*) The split-phase locomotive; (*c*) The industrial frequency phase convertor locomotive.

Brief details are also given of three experimental types of German locomotive designed to operate on a 20,000 volt 50 cycle supply.

The Motor-Generator Locomotive. In brief, the motor-generator locomotive obtains a supply of power from a high-tension single-phase system, reduces the voltage by means of a transformer or auto-transformer, and then converts the power to direct current by means of a synchronous motor-direct current generator set. The output from this machine is then fed to the traction motors which are generally connected in parallel, although motor-combinations can be employed if catered for in the design.

The power circuit diagram of a typical motor-generator locomotive is shown in Fig. 95. Power is supplied at 11,000 volts 25 cycles A.C. and passes through a circuit breaker to the main transformer, this latter being of the air-blast type with a rating of 2000 KVA. A single-phase synchronous motor with a rating of 1770 KVA is connected to the transformer secondary winding and drives a 1500 KW generator with two exciters, a main exciter and a regenerative exciter. Of these, the main exciter provides excitation for the synchronous motor rotor, and the regenerative exciter field together with current for battery charging and driving the compressor, etc. The regenerative exciter is employed solely for separate excitation of the traction motor fields during regenerative braking or when required to obtain special motor characteristics.

The M.G. set is started from the battery by closing contactors ST1, ST2 followed in sequence by ST3, ST4, this action accel-

erating the machine to approximately thirty per cent. of normal speed. Further increases are then obtained by induction motor action using contactors ML, SL, RL, L until synchronous speed

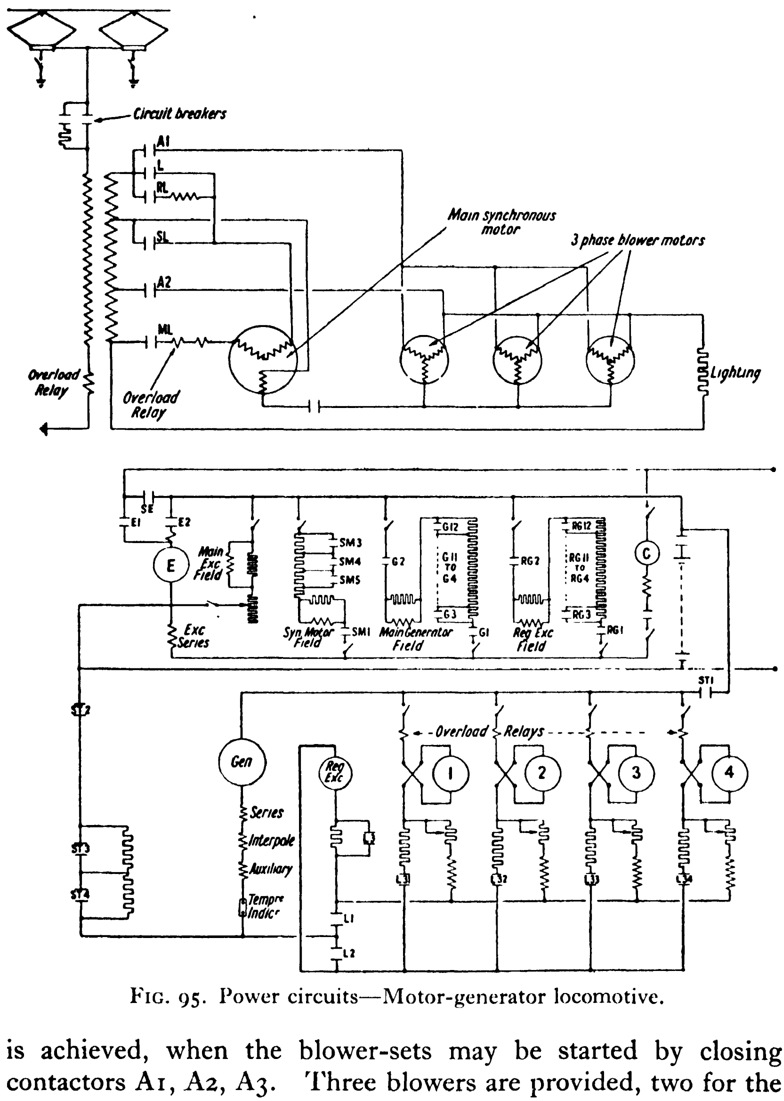


FIG. 95. Power circuits—Motor-generator locomotive.

is achieved, when the blower-sets may be started by closing contactors A1, A2, A3. Three blowers are provided, two for the traction motors and one for the transformer, each being driven by a 10 h.p. three-phase induction motor whose supply is derived

from tappings on the transformer and a quadrature winding on the synchronous motor.

Acceleration and speed control of the locomotive is carried out by control of the main generator field excitation through the medium of several small contactors arranged to give 29 running notches, a system which reduces the number of heavy-duty contactors required to four only, one in each traction motor circuit as a circuit-breaker. Reversal is carried out by the changing of the armature connections of the motors, the use of this more uncommon method being due to the scheme of connections

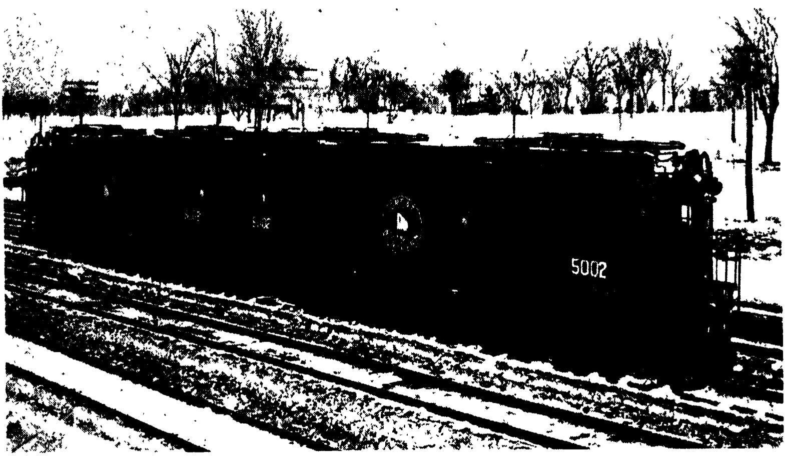


FIG. 96A. Two-unit Motor-generator locomotive.

employed in order to permit separate excitation of the motor fields when required. For normal excitation contactor L1 is closed ; and for separate excitation contactors L2, L31, L32, L33, L34 are closed, the resistances in the circuits of these latter being arranged so as to carry both armature and excitation currents in order to achieve stability during braking. When regenerating, the synchronous motor delivers single-phase power back to the overhead line through the main transformer, energy being derived from the traction motors functioning as generators and employed to drive the main-generator as a separately-excited D.C. motor.

The locomotives are designed to operate in pairs, two such units being shown in Fig. 96A, together with a plan of a single machine. Four nose-suspended traction motors give a total of 2215 h.p. at

the one-hour rating and a maximum tractive effort of 69,000 lbs., this being made possible by the adhesive weight of 127 tons corresponding to a loading of 31¾ tons on each of the four axles. The total weight of the locomotive is 165 tons and its wheel arrangement 1–D_0–1, a pony truck being included at each end of the rigid wheelbase. The locomotives are designed for operation on the Great Northern Railroad 73 mile section in the Cascade Mountains in North-Western U.S.A., a route which includes the Cascade tunnel, and are geared for a maximum speed of 45 m.p.h.

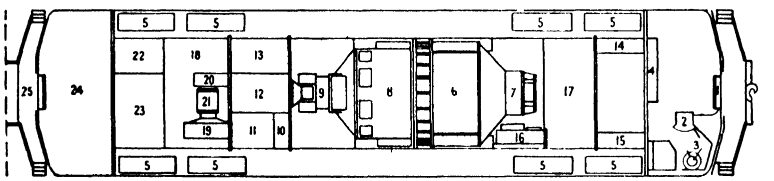


FIG. 96B. Plan of one unit of Motor-generator locomotive.

1. End doorway.
2. Master controller.
3. Air-brake controller.
4. Control switch cabinet.
5. Batteries (under floor).
6. Synchronous motor.
7. Exciter.
8. D.C. generator.
9. Regenerative exciter.
10. Reverser.
11. A.C. line contactors.
12. Resistance chamber.
13. D.C. line contactors.
14. M.G. starting contactors.
15., 16. Relay cabinet.
17. Blower cubicle.
18. Main transformer.
19. Blower fan.
20. Ducting.
21. Blower motor.
22. Main circuit-breaker.
23. Voltage Regulator.
24. Rear driving cab.
25. Corridor connection to other unit.

Turning to the plan, it will be noted that the usual driving positions are installed at each end and connected by two corridors, one down each side of the locomotive, a method allowing ample access to the electrical equipment which is only possible due to the width of eleven feet permitted by the spacious American loading gauge. The layout of the various items of equipment is indicated on the plan and needs no elaboration. Situated on the roof of the superstructure are two double-pan pantographs of the spring-raised air-lowered pattern.

Another interesting example of a motor-generator system is that installed on the French National Railways C-C shunting locomotive, illustrated in Fig. 97, in which the main motor of the set is supplied with direct current at 1500 volts and four series wound nose-suspended traction motors are connected in series with the

generator. Field control of this latter is employed for speed variation and, as no starting resistances are necessary, the locomotive can operate continuously at any speed and on any controller position.

Considerable interest is attached to two new types of motor-generator locomotive now under construction in the U.S.A. These are :

(*a*) Four double-unit 440 ton 6800 h.p. locomotives for the Virginian Railroad, wheel arrangement B_0–B_0 + B_0–B_0 on each unit.

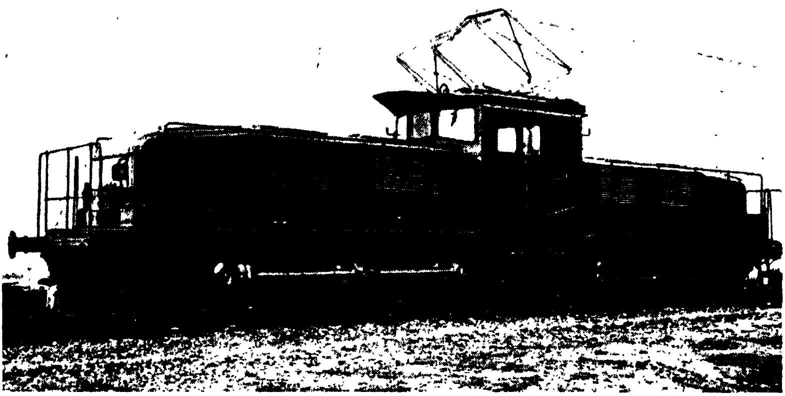


FIG. 97. French motor-generator shunting locomotive.

(*b*) Two 320 ton 5000 h.p. locomotives for the Cascade section, Great Northern Railroad, wheel arrangement B_0–D_0 + D_0–B_0.

The Split-Phase Locomotive. The split-phase or phase-convertor locomotive is one which collects single-phase power from the trolley wire and converts it to three-phase power at a lower voltage through the medium of a rotary phase-convertor operating in conjunction with a transformer. Traction motors of the three-phase induction type are used and, due to the constant speed characteristics of these machines, locomotives of this type are only used where a constant speed haul is required over a route where undulating gradients occur. Very few running speeds are obtainable, e.g. in the locomotive described below only two speeds are provided, these being 14 and 28 m.p.h. obtained by operation of the traction motors as 8-pole and 4-pole machines respectively.

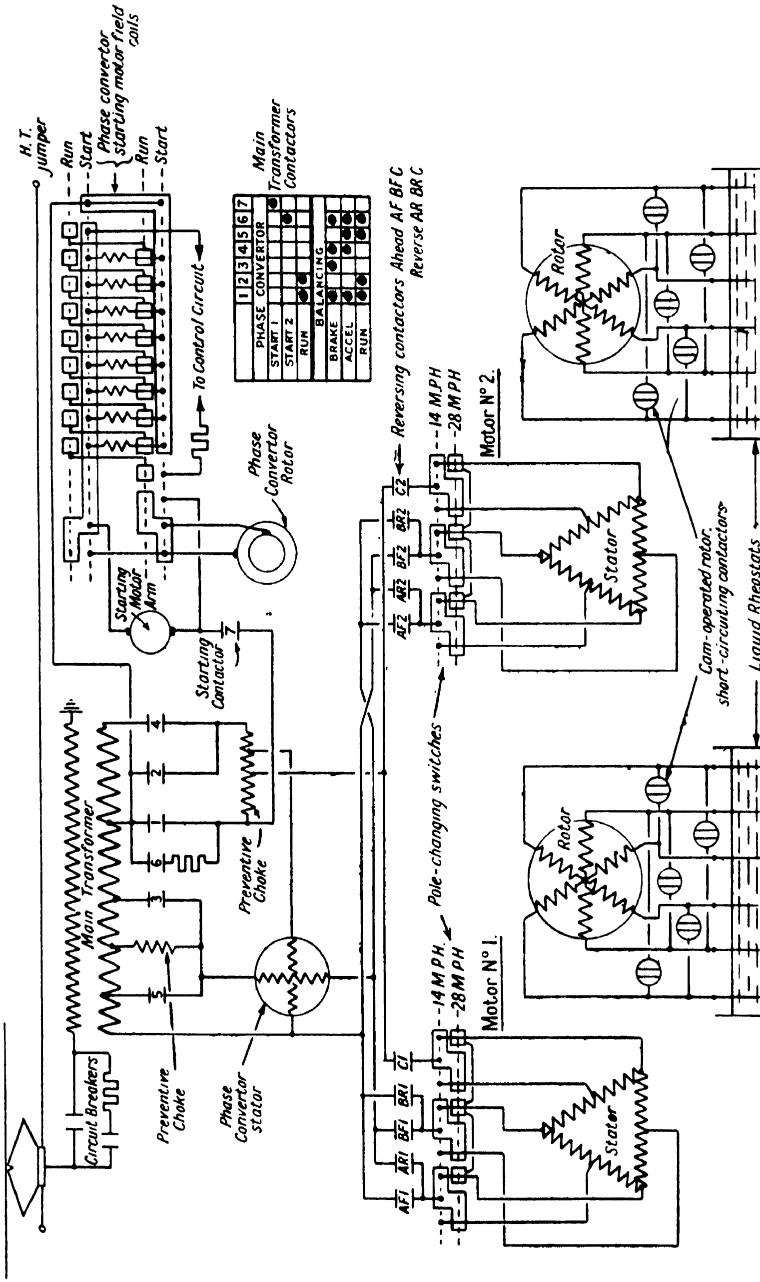


Fig. 98. Power circuits—split-phase locomotive.

The power-circuit diagram of such a locomotive is shown in Fig. 98. High-tension supply is collected from the trolley-wire by one pantograph and, as the locomotives always operate in multiple unit with up to four units coupled together, adjacent locomotive pantographs are connected by a high-tension bus-bar mounted on the roof with a flexible jumper to bridge the gap between the superstructures, a most unusual method. After collection, the line current passes through a circuit-breaker and overload relay to the primary of the main transformer and thence to earth through the running rails.

The phase-convertor is a two-phase synchronous machine with a motoring and a generating winding, these being so wound as to be 90 electrical degrees out of phase with each other. Two-phase to three-phase T-connection between the generating winding and the secondary of the main transformer results in a three-phase supply being available at the following three terminals :

(*a*) One end of the motoring winding.
(*b*) One end of the generating winding.
(*c*) The main preventive coil.

For starting the phase convertor a small series motor is employed and, when running, this machine is used for excitation of the phase-convertor rotor.

Power at 1150 volts is supplied to the traction motors through the pole-changing switch-groups and reversing contactors. For forward operation contactors AF1, BF1, C1, AF2, BF2, C2 are closed and for reverse AR1, BR1, C1, AR2, BR2, C2, reversal being accomplished by crossing over the A and B wires on the motor terminals, the standard method of reversal for a three-phase machine. Pole-changing is carried out by an electro-pneumatic drum-type switch, which operates only when no motor current is flowing and by means of its contacts arranges the motor stator winding connections to give either a four or eight-pole field system. Each traction motor has a wound rotor, and both ends of all three phases are brought out to six slip-rings. The six leads connected to the associated brush-gear are carried to fixed electrodes in a liquid starting resistance which uses a solution of soda-ash as the electrolyte. The motors are accelerated by slowly raising the level of the electrolyte under the control of a moving gate and on reaching the running speed each phase is short-circuited by means of the contactors D1, etc.

Regeneration is inherent in this type of locomotive as, when the traction motor speed rises above synchronous, power is automatically fed back into the trolley-wire, and, in consequence, when operating over an undulating route, the locomotive travels at an approximately constant speed, absorbing or returning power according to the trend of the gradient without any alteration in the controller position.

Three of these locomotives connected together for operation in multiple-unit are shown in Fig. 99. The wheel arrangement of each unit is 1–BB–1, each pair of driving axles being connected

FIG. 99. Three unit split-phase locomotive.

together and having its inner crankpins driven by connecting rods from a jackshaft mounted between the outer driving axle and the pony truck. One traction motor drives each jackshaft through twin-gears and is capable of developing 850 h.p. at 14 m.p.h. or 1000 h.p. at 28 m.p.h. on the continuous rating. The general layout of the locomotive is such that the transformer and phase-convertor are mounted over the driving wheels, and flanked at each end by two compartments in which are situated the traction motors and other equipment.

The Industrial Frequency Locomotive. Electric locomotives which operate from an alternating current supply almost universally employ a low-frequency such as $16\frac{2}{3}$ or 25 cycles per second, in order to obtain satisfactory operation from the A.C.

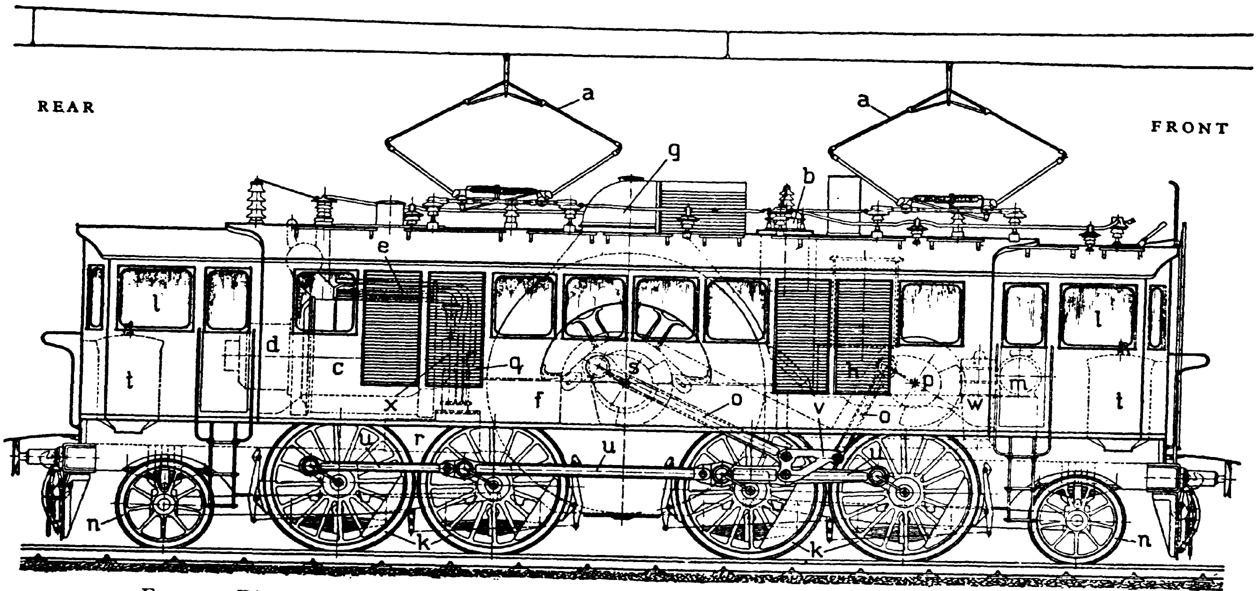


FIG. 100. Diagrammatic view of Hungarian passenger locomotive for operation on 50 cycle A.C. supply.

a. Pantograph.
b. Main oil circuit breaker.
c. Phase-convertor.
d. Exciter.
e. Oil and water coolers for phase convertor.
f. Main 2500 h.p. traction motor.
g. Main traction motor fan.
h. Liquid starter.
k. Driving wheels.
l. Driver's cab.
m. Compressors.
n. Trailing wheels.
o. Side rods.
p. Auxiliary crankshaft.
q. Cooling water circulating pump.
r. Cooling water tank.
s. Driving crank on main motor.
t. Master controller.
u. Coupling rods.
v. Kando frame.
w. Pumps for liquid starter.
x. Auxiliary pump for cooling water.

series-commutator motor. To obtain this low-frequency supply, the railway company has the choice of two methods : either special generating stations solely for the traction supply must be used, or power may be purchased at industrial frequency (e.g. 50 or 60 cycles per second) and the requisite supply obtained by the use of rotary converting equipment. As a result, locomotive engineers have long been interested in the development of motors and control systems suitable for direct operation on these industrial frequencies.

The most interesting examples of this type of locomotive at present in service are those of the Hungarian State Railways, designed by Dr. Kando and constructed by the Royal Hungarian State Engineering Works. There are two types of locomotive, e.g. passenger and freight, with wheel arrangements 1–D–1 and E respectively. As the electrical equipment is identical in both types, this description is confined to the passenger locomotive which is shown diagrammatically in Fig. 100.

A method of control is employed which is similar in certain details to that outlined for the split-phase locomotive. Power is collected from the 15,000 volt 50 cycle supply by two single-pan pantographs and, after passing through a main oil-immersed circuit-breaker, the current is taken to the primary winding of a phase-convertor whose function is to convert the single-phase high-tension energy to multi-phase current at 1000 volts for supplying to the traction motor.

The phase-convertor is a four-pole synchronous machine possessing primary and secondary windings, and has a rotor of turbo-generator type construction, excited by direct current from an exciter on the rotor shaft. Two main windings are situated on the stator ; a primary winding of the concentric type with one end connected to the 15,000 volt supply and the other to earth, insulation being graded accordingly ; and a secondary winding of the barrel type, insulated throughout for a working pressure of 1200 volts. This latter winding forms a closed ring and has tappings at eight places from which three, four or six-phase power may be obtained as required. Low-tension current for operation of the auxiliaries is obtained from a further winding on the stator, where it is induced by transformer action. The convertor set runs at 1500 r.p.m. and is accelerated to its running speed by means of a special starting motor built into

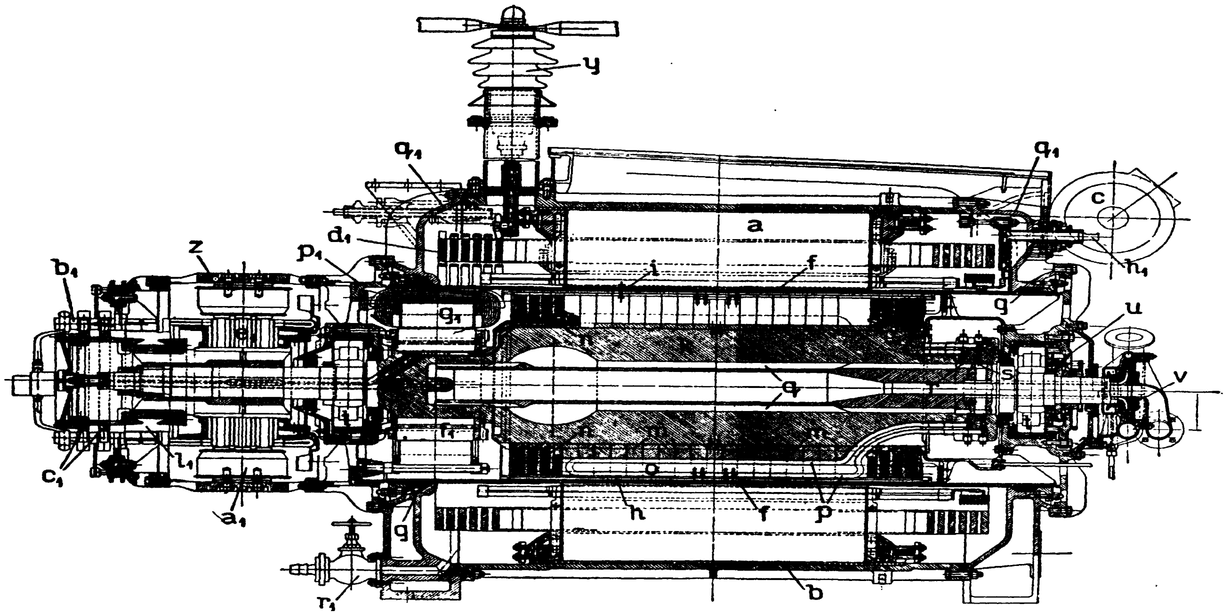


FIG. 101. Cross section of phase-convertor.

- *a*. Stator core.
- *b*. Cast-iron stator case containing the oil.
- *c*. Circulating pump for cooling oil.
- *f*. Bakelite paper tube.
- *g*. Gland for bakelite tube.
- *h*. Damper winding.
- *i*. Air-gap between stator and rotor.
- *k*. Rotor shaft.
- *l*. Grooves in rotor shaft.
- *m*. Segmental rotor teeth.
- *n*. Rotor winding.
- *o*. Slots for cooling elements.
- *p*. Cooling elements.
- *q*. Bore-hole in rotor-shaft for cooling water circulation.
- *r*. Cooling-water inlet.
- *s*. Cooling-water outlet.
- *t*. Roller bearing for rotor shaft.
- *u*. Thrust bearing for rotor shaft.
- *v*. Cooling water circulating pump (mounted on shaft end).
- *y*. Porcelain bushing insulator.
- *z*. Exciter yoke.
- a_1. Main poles of exciter.
- b_1. Exciter brush-holder.
- c_1. Slip-rings (outside exciter).
- d_1. Coil-ends of phase-convertor primary winding.
- e_1. Exciter armature.
- f_1. Starting motor rotor.
- g_1. Starting motor rotor.
- h_1. Phase-convertor secondary terminals.
- l_1. Exciter commutator.
- p_1. Exciter end-bearing housing.
- q_1. Phase-convertor end-shields.
- r_1. Oil outlet.

the frame. A cross-sectional drawing of the convertor appears in Fig. 101.

The most interesting feature of this phase-convertor is the method adopted for cooling in which the stator windings are completely immersed in oil, the necessary enclosure being provided by a bakelite cylinder passing through the air-gap of the machine and incorporating an oil-tight expansion joint at one end. Oil from this system is continuously circulated by means of a motor-driven pump through a cooler situated on top of the machine. The rotor is cooled by water, which is circulated through a number of copper tube cooling elements built into the core and then pumped to another cooler also situated on top of the machine. An air-circulation system is then employed to dissipate the heat from the two coolers, air being drawn from the atmosphere, passed through the coolers and expelled through the roof by means of a powerful motor-driven fan.

The output from the eight secondary terminals of the phase-convertor passes to the pole-changing switch-group, which is mounted adjacent to the main motor, and whose function is to make the necessary connections between the secondary tappings of the phase-convertor and the sliprings of the motor, in order to give, as required, combinations of 72, 36, 24 or 18 poles corresponding to synchronous speeds at the motor shaft of 83, 167, 250 and 333 r.p.m. This switch-group consists of twenty-eight contactors fitted with self-induced blowouts and arc chutes, whose operation is controlled by a manually-operated camshaft which selects the contactors it is required to close, actual movement of the contacts being carried out by compressed air when the selection is completed.

Only one traction motor is fitted in each locomotive, and this drives the road wheels by means of side rods operating in conjunction with a Kando frame, the drive to which is taken from two cranks, one at each end of the motor shaft. As this is only a single-motor equipment, it was necessary to incorporate an auxiliary dummy-shaft complete with cranks and connecting rods in order to ensure that this drive would function correctly. The traction motor is rated at 2500 h.p. on the one-hour capacity, and has a five-minute peak rating of 3500 h.p. on its two higher speeds. It is wound as a special type of polyphase induction motor with four economical running speeds, which are obtained by means of

two independent primary windings mounted on the rotor, connections to these windings being controlled by the pole-changing contactor group. A secondary winding is fitted on the stator and is so designed that it will respond to every pole combination in the primary.

The motor shaft is made from a steel forging splined to carry a single steel disc 76 inches in diameter. Stiffening ribs cut from steel plate assist in supporting this disc, the whole assembly being welded together and subsequently annealed. Wherever possible, circular holes are drilled in this assembly to reduce the weight to a minimum. Outside this hub, and bolted to it, is a steel framework which carries the rotor laminations, these being of the segmental type held by dovetail keys, and forming a total of 540 slots of the semi-closed type which contain the two independent windings comprising the rotor circuits.

The outer winding is a normal barrel winding connected to six slip-rings and arranged that when connected to a three-phase supply either 36 or 72 poles may be obtained. The inner winding is specially devised to produce 24 poles when excited from a six-phase supply and 18 poles from a four-phase supply, this feature requiring ten slip-rings each connected to differing points in the winding. By these arrangements the following running speeds are made available :

Passenger locomotive	15·5	31·0	46·5	62·0 m.p.h.
Freight locomotive -	10·6	21·2	31·8	42·5 m.p.h.

The secondary winding is accommodated in 576 stator slots and has 144 winding sections in order to accommodate the four primary pole connections. These sections are connected in series in sets of three, which are then combined to form a closed polyphase winding with 48 tappings, each tapping being connected to a separate electrode in the liquid starting resistance.

Cooling of the traction motor is accomplished by an air-stream drawn in through louvres in the side of the locomotive, passed to the centre of the rotor and thence through axial ducts in the rotor and stator to the outer casing, from where it is ejected through ventilators in the roof by a motor-driven fan situated above the stator core.

The liquid starter comprises an electrolyte reservoir with an electrode chamber mounted above it, the level of the liquid in this chamber being regulated by a weir raised and lowered by a

pneumatic-hydraulic engine. Electrolyte from the reservoir is pumped continuously into the electrode chamber and returns thereto over the weir.

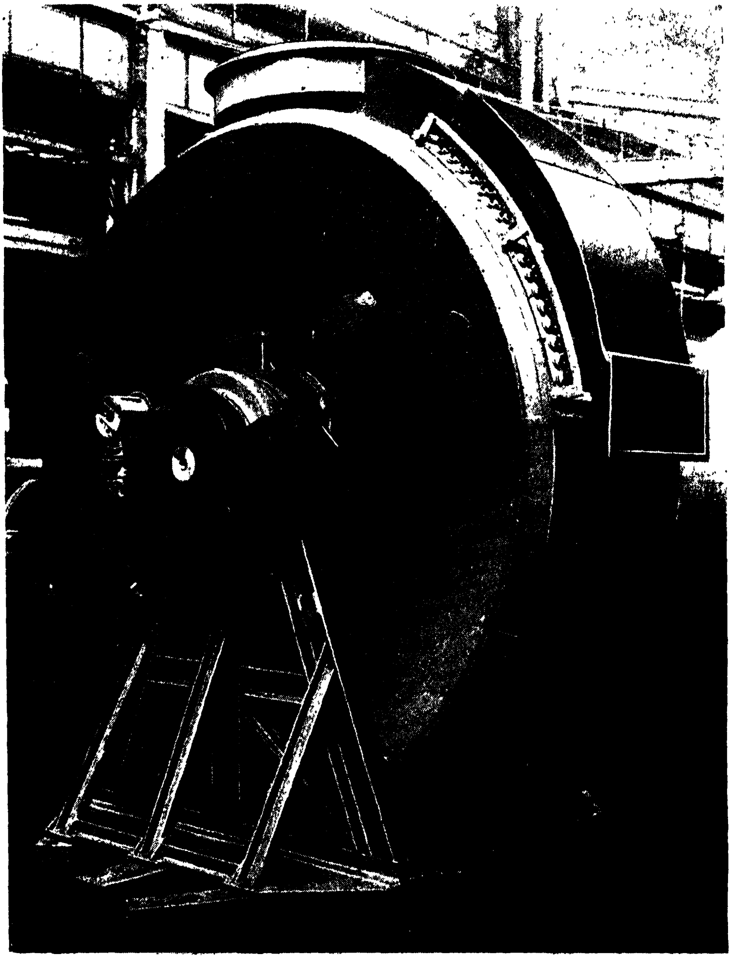


FIG. 102. 2500 h.p. traction motor.

Fig. 102 shows a view of the traction motor ; Fig. 103 the pole-changing switch group and the liquid starting resistance. In operation the driver moves the speed selecting lever to the desired position (the first if starting from rest), this action setting the

switch group to the correct position for the pole-combination required. On turning over the handle of the speed control lever, the switch group closes and connects the motor to the phase-convertor, after which movement of a second lever raises the excitation on this latter until the locomotive begins to move. A system of watt-relay control then comes into operation and governs the rate at which resistance is reduced in the liquid starter during acceleration to that at which the motor has the highest efficiency and best power-factor. When the running speed is attained, the phase-convertor excitation is reduced and then automatically

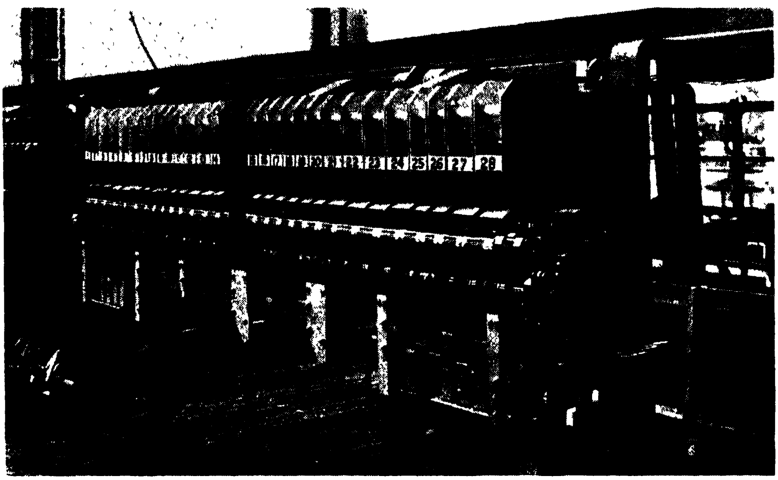


FIG. 103 (i). Pole-changing switch group. Hungarian industrial frequency locomotive.

regulated to that necessary for maintaining a constant speed as the gradient varies. To change to another speed, all power is cut off and the speed selecting switch moved, after which the system again functions as just outlined.

Full dimensions and other details of the locomotive appear in the Appendix, page 317.

German Industrial Frequency Locomotives. Of the four experimental locomotives built in 1936 for the Höllenthal section of the German State Railways, where a supply of 20,000 volts 50 cycles A.C. is employed, three may be classed as convertor type locomotives. The fourth machine has specially-designed single-

phase commutator motors. The mechanical construction of all the four is very similar, the wheel arrangement being B_0–B_0 in each case. The electrical equipments are the products of four different manufacturing concerns and each employs an entirely

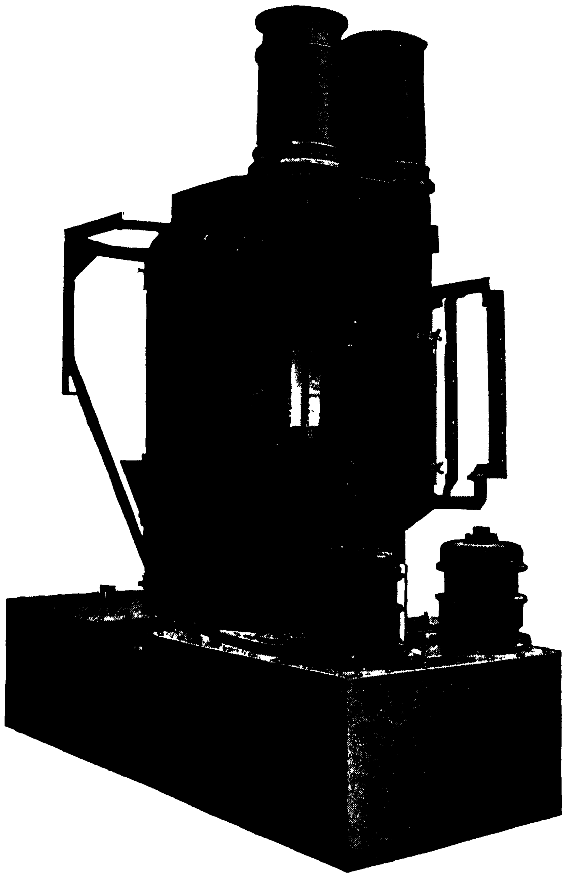


FIG. 103 (ii). Liquid starting resistance. Hungarian industrial Frequency locomotive.

different method of control, in the case of the convertor locomotives these being as follows.

The first locomotive is fitted with four standard D.C. series traction motors supplied from the secondary of the main transformer through a rectifier, starting and speed control being effected

by reduction of the rectifier output voltage through the medium of a high-tension tap-changer operating on the transformer primary. Electric braking of the rheostatic type is included in the system, the motors being self-excited and loaded on to a braking resistance.

The second unit employs a similar arrangement to the first with the exception that starting and speed regulation is carried out by grid control of the rectifier, supplemented by series-parallel combination and field-reduction of the motors. Grid control is arranged to vary the voltage by two methods, partly by retarding anode ignition, and partly by the selection of one of two sets of anodes supplied at different voltages from the secondary of the main transformer, operation of the control being governed by the position of the master controller handle. Rheostatic braking is again employed, but the motors in this case are separately excited through the rectifier from a tapping on the transformer secondary.

The third locomotive has a phase-convertor and a three-phase induction motor on each axle, making a total of eight machines. Each phase-convertor has a wound rotor and stator, between which runs a free intermediate rotor excited with direct current, this latter providing the necessary rotating field. Three arrangements of these machines are made for running :

(*a*) All eight machines act as driving motors, the convertors and induction motors being connected in cascade.

(*b*) The convertors only act as motors.

(*c*) The induction motors are supplied from the stators of the phase-convertors which themselves develop no driving torque.

From this it will be noted that during starting and when running on reduced speed the phase-convertors act as motors. Electrolytic rotor resistances are used for intermediate speeds and acceleration purposes. Regenerative braking is inherent in all machine combinations when the speed rises above synchronism.

CHAPTER EIGHT

DIESEL ENGINES AND TRANSMISSION SYSTEMS

THE diesel-electric locomotive differs from the normal electric locomotive in that it carries its own prime-mover and in consequence is independent of external power supply systems, requiring only a periodical replenishment of fuel, lubricating oil, water, etc. The prime-mover concerned is, of course, the diesel engine which is usually defined as a reciprocating engine, actuated by the gases resulting from the combusion of a liquid fuel-oil, injected in a fine state of diffusion into the cylinder at approximately the conclusion of the compression stroke, and in which the sole means of igniting the charge is by the heat generated due to compression of the air in the cylinder.

The Two- and Four-Stroke Cycles. In operation, the sequence of events may be carried out on either a two-stroke or four-stroke cycle depending on the design to be adopted.

Commencing with the four-stroke cycle, the sequence is made up as follows :

(1) A down or " suction " stroke during which air is drawn into the cylinder through the inlet valve.

(2) An up or " compression " stroke during which, as all valves are closed, the air is compressed, and, at the conclusion of which, the liquid fuel is injected as a finely-divided spray.

(3) The combustion and expansion stroke during which the fuel burns and the resultant gases expand so driving the piston downwards.

(4) Finally, an up or " exhaust " stroke where the waste gases are expelled through the exhaust valve under the action of the rising piston.

The two-stroke cycle, with the aid of a scavenging blower which provides large volumes of air at a moderate pressure, eliminates the need for the " suction " and " exhaust " strokes, and enables the engine to double the number of working strokes for a given speed, resulting in an increase of power to almost double that for the four-stroke cycle, small losses being incurred by incomplete

scavenging (i.e. clearing away of the exhaust gases), and in driving the blower. The modified cycle of events is as follows, referred to Fig. 104.

(1) At the lower end of its downward stroke, the piston uncovers a row of ports in the cylinder wall, thereby admitting scavenging air to the cylinder. This flow of air through the ports and exhaust valves leaves the cylinder full of clean air when the piston covers the ports on its upward stroke.

(2) As the piston continues on the upward stroke, the exhaust valve closes and the charge of air is compressed to a small fraction

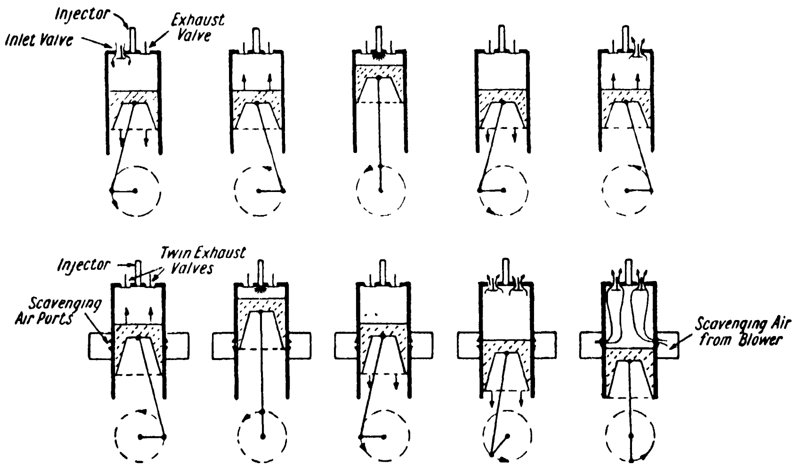


FIG. 104. The four-stroke cycle as applied to a diesel engine.
The two-stroke cycle as applied to a diesel engine.

of its original volume at a pressure of the order of 600 lbs. per sq. in. Air, when compressed to this extent, increases in temperature to approximately 550°C. This high compression ratio is maintained at all loads and speeds, as the air intake is never throttled.

(3) Shortly before the piston reaches top-dead centre, the liquid fuel, atomised by high-pressure, is injected into the combustion chamber and is ignited by the high temperature of the air therein. It continues to burn until the charge is consumed, thereby rapidly building up a high pressure which acts upon the piston, forcing it downward on the power stroke.

(4) Just before the piston reaches the end of the power stroke, the exhaust valves open, releasing the gases to atmosphere. The piston then covers the air inlet ports. By this time the exhaust

gases have expanded to the point where the pressure is lower in the cylinder than in the air storage reservoir.

The whole cycle is then repeated. Note that the air inlet is through ports in the cylinder sides, only the exhaust valve being in the cylinder head, a function which is reversible if required.

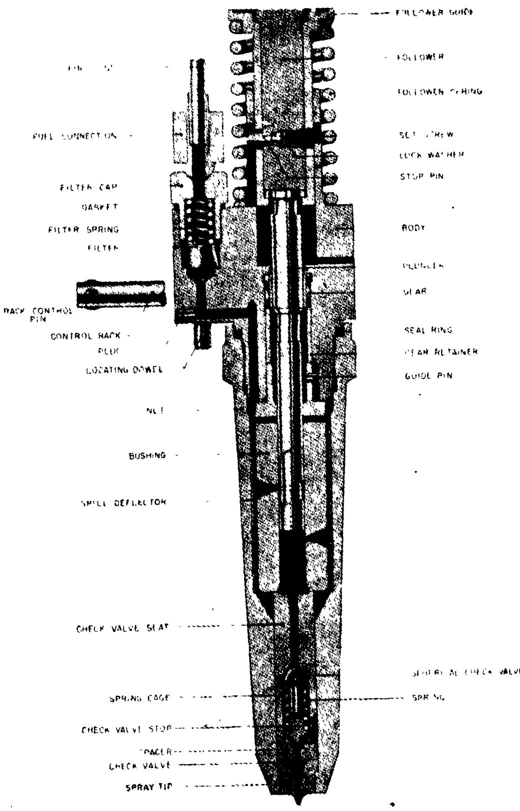


FIG. 105. General Motors combination injector fuel-pump unit.

Before proceeding to discuss typical engines of these types, some details of the injection system, blowers, etc., now follow.

Injection System. Injection may be made directly into the cylinder head, or into a small ante-chamber, as in engines fitted with pre-combustion chambers, Ricardo air-cells, etc., where this

auxiliary chamber is an attempt to obtain better atomisation of the fuel and more efficient running. The majority of railway oil engines, however, employ the former system, i.e. direct injection into the cylinder head.

Fuel is pumped from the main tank to supply a series of injector fuel pumps, one for each cylinder of the engine. These pumps are operated by an engine-driven camshaft, frequently the valve camshaft, and are arranged to supply a certain amount of fuel to the injectors situated in the cylinder heads, the amount delivered being under the control of the engine governor. Various groupings and combinations of the components of such a system are possible, an excellent example of which is the Electromotive (General

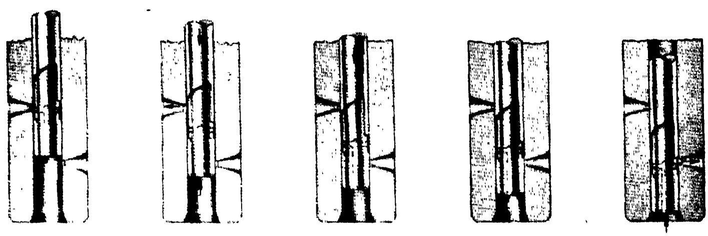


FIG. 106A. One complete down stroke of injector plunger at "half-load" position.

Motors) combination injector pump, illustrated diagrammatically in Fig. 105.

Each cylinder is equipped with one of these injector-pump units. The injector is seated in a tapered hole in the centre of the cylinder head, so that the end of the injector is flush with the bottom of the cylinder head. All external working parts are lubricated with engine oil which flows from the end of the rocker arm to the top of the plunger follower guide. Internal mechanism is lubricated and cooled by the fuel oil flowing through the injector.

Fuel oil enters the injector, passes through a bronze filter in the inlet passage and fills an annular supply chamber around the bushing. The surplus fuel flows out of this chamber through another bronze filter in the outlet passage, and this filter serves to

prevent any reverse flow of fuel from carrying dirt into the injector when the engine is shut down.

Fuel is injected into the cylinder by the reciprocating motion of the plunger, the flow of fuel through the injector during one complete downstroke of the plunger being shown in Fig. 106A. The plunger is operated by a rocker arm from the camshaft and has a constant length of stroke. The quantity of fuel injected into the cylinder is controlled by rotating the plunger, the " effective stroke " (i.e. portion of the stroke when injection is actually taking place) at various engine load and plunger positions being shown in Fig. 106B. The plungers on all units are rotated by the control rack which engages pinion teeth on the plungers them-

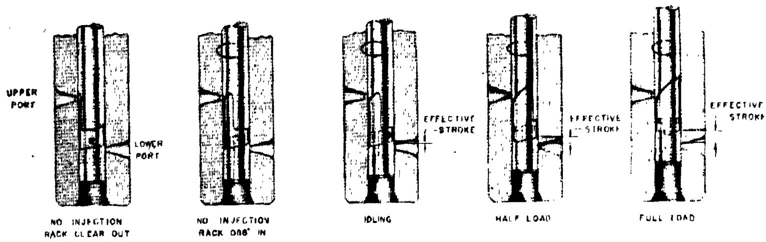


FIG. 106B. Diagram showing how the quantity of fuel injected is controlled by rotating plunger with control rack.

selves, this rack being operated by a lever connected to the injector linkage on the governor.

In the C.A.V.-Bosch fuel injection system, used extensively in Europe, the injectors are situated in their appropriate cylinder heads, and the injection pumps are mounted either singly adjacent to the valve-gear camshaft from which they are operated, or grouped together with their own driving mechanism, an arrangement very popular on small high-speed engines as used in railcars and for omnibuses.

Superchargers and Blowers. Two types of blower are applied to railway oil-engines, the exhaust gas turbine-driven type and the mechanically-driven type.

The former, as exemplified by the Buchi and Rateau models, comprises a small high-speed single-stage turbine, to which are

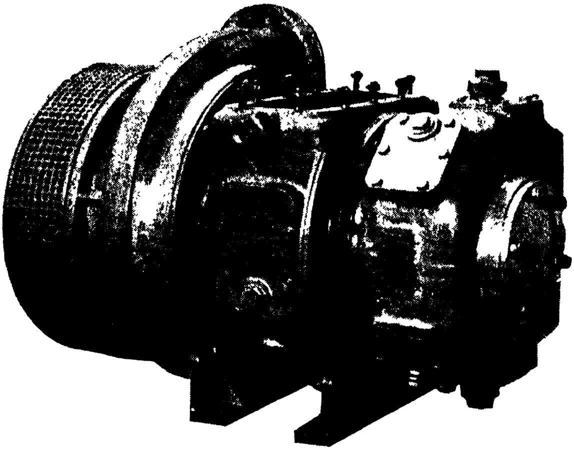


FIG. 107A. Exhaust-gas-turbo-blower.

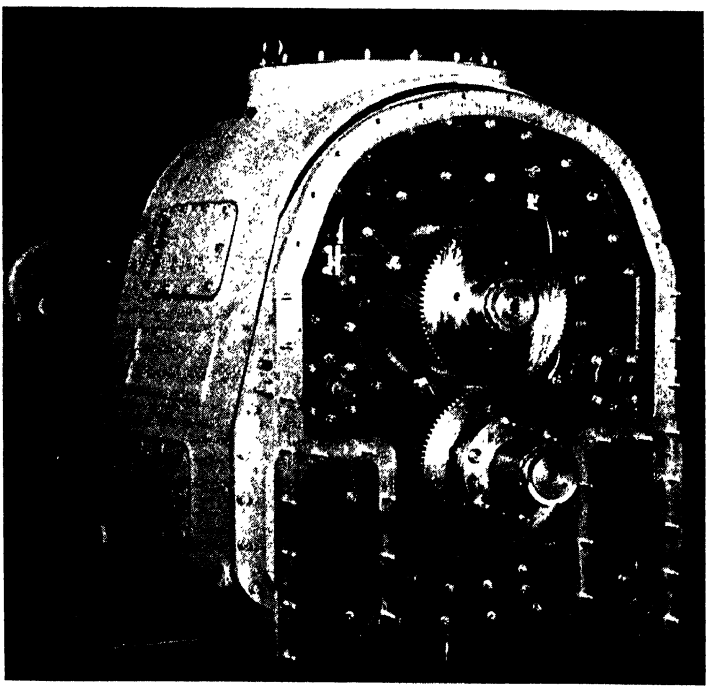


FIG. 107B. Mechanically-driven scavenging blower.

fed the exhaust gases from the engine. This turbine is direct-coupled to a small blower fan which supplies air under pressure to the engine. A typical unit is shown in Fig. 107A. The use of superchargers of this type is confined to four-stroke engines where its inclusion means an increase of up to fifty per cent. in the maximum output, this due to increased mean effective pressure and efficient scavenging obtained.

Fig. 107B shows a typical mechanically-driven scavenging blower as used on two-stroke engines. It consists of a pair of lobed aluminium rotors which revolve in a closely-fitted aluminium housing, each rotor having three helical-shaped lobes. This type of construction produces a large volume of air at low pressure, and ensures a positive supply of air to the engine regardless of speed and load. Each rotor is pressed on to a tubular steel shaft, one end of which fits into the rear bearing block in the blower housing, whilst the other end fits into a serrated flanged hub which forms the outer bearing journal and carries one of the two matched driving gears.

Examples of the fitting of these two types appear in the engine descriptions immediately following.

Typical Engines

Electromotive (General Motors): U.S.A. The model 567A diesel-engine, the six-cylinder version of which is illustrated in Fig. 108 is a V-type, i.e. one in which two banks of cylinders are utilised, set at an angle of 45° to each other and arranged to drive a common crankshaft. It is a two-stroke engine incorporating the advantages of low weight per horsepower, fully scavenging air-system, solid unit direct injection and full-horsepower development at low engine speeds. The cylinders are $8\frac{1}{2}''$ bore by 10″ stroke with a compression ratio of 1 to 16. Idling speed is 275 r.p.m. and maximum speed 800 r.p.m., an overspeed trip mechanism being provided which stops injection when the speed reaches 880 r.p.m. Four models are available with 6, 8, 12 and 16 cylinders developing a rated horsepower of 600, 800, 1000, 1350 respectively. Improvements are now being made which will raise the power of the 16-cylinder model to 1500 h.p., which with a weight of 31,000 lbs. will give a power-weight ratio of 20·7 lbs. per b.h.p. The 600 and 800 h.p. engines have one blower and the two larger units, one blower per bank of cylinders.

The crankcase is a fabricated steel structure supporting the main bearing frames and of which the engine top deck casing, cooling water and lubricating oil manifolds form an integral portion. Steel-headed retainer castings in the top casings are counterbored to carry the cylinder liner and cylinder head assembly. The whole crankcase and cylinder structure assembly is held in rigid alignment by horizontal and vertical stress-plates. Two plates,

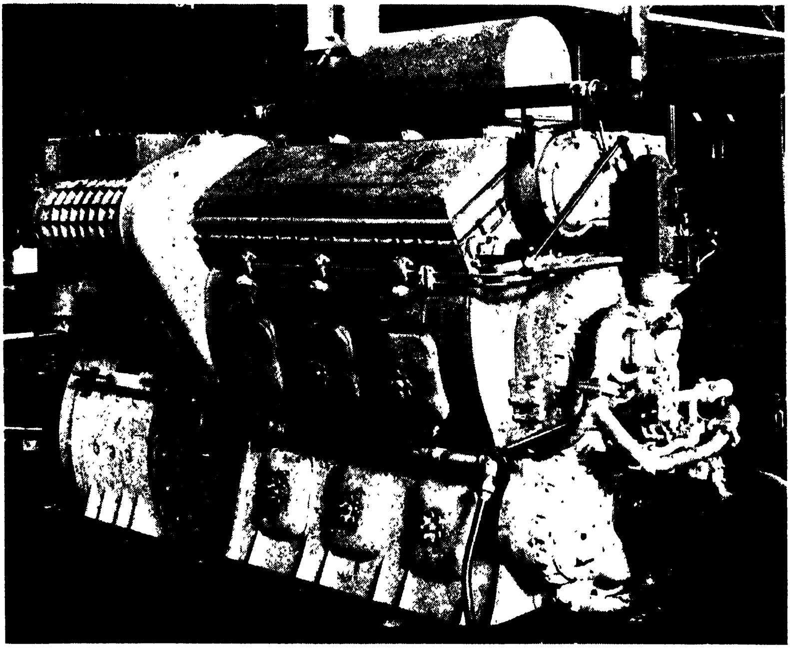


FIG. 108. 6-cyl. Electromotive two-stroke engine-generator set.

welded parallel to each other at the bottom of the crankcase, form the cooling water manifold and are bored to receive the cylinder liners, a rubber seal ring being fitted between liner and plate to prevent water leaking into the "air box" or scavenging air reservoir.

Cylinder liners are made of close-grained high-strength alloy cast iron with a cored annular space for the water-jacket. The scavenging air inlet ports are located in the wall of the liner just above the position corresponding to the top of the piston when it is at the bottom of its stroke.

The scavenging air reservoir is the space enclosed by the crankcase ends and sides, and the upper and lower casings, provision being made for draining condensation and oil leakage from this box through pipe connections, and for inspection, servicing and cleaning by hand-holes fitted with cork sealing gasketed covers.

Cylinder heads are made of alloy cast iron, cast with cored water passages to match openings in the liners. They are clamped into the counterbored retainer head and sealed by synthetic rubber seal-rings. Each cylinder head is equipped with four exhaust valves, symmetrically positioned around a combined injector-pump unit and all actuated by rockers from the adjacent camshaft.

A cross-section of the engine appears in Fig. 109.

Alloy cast iron pistons of the two-piece or " floating " type are utilised in which the body of the piston is supported on a piston pin carrier which is held in position within the piston by a $\frac{3}{16}''$ snap ring, a copper thrust washer being inserted between piston pin carrier and piston bearing plate. This type of construction permits more effective cooling of the piston crown, better lubrication and more even distribution of wear and load.

The connecting rods are of the interlocking blade and fork rod construction in which the blade-rod is held in place by a counterbore in the fork rod.

The crankshaft is a drop forging made of carbon steel with electro-hardened main and crankpin journals and with drilled passages to carry a continuous flow of lubricating oil to the main and connecting rod bearings. The 16 cylinder crankshaft is in two sections with two centre main bearings ; the others are all in one piece. No flywheel is fitted, the main generator armature, attached to the crankshaft by a flexible coupling, possessing ample inertia. A harmonic balancer is located at the front end of the crankshaft and consists of a two-piece hub, laminated springs and a rim. Its function is to damp the torsional vibration inherent in all crankshafts. Adjacent to this balancer is the accessory driving gear for driving water and oil pumps, camshafts and the main governor.

The oil pan is a fabricated steel base which functions as a reservoir for the engine oil and is designed to slope to a central sump from which the oil-pump feed is taken. The bottom of the crankcase is bolted and dowelled to this oil pan, both surfaces being machined, and inspection hand-holes are provided directly

beneath those in the air reservoir for servicing the lower parts of the engine, e.g. crankshaft, connecting rod bearings and main bearings.

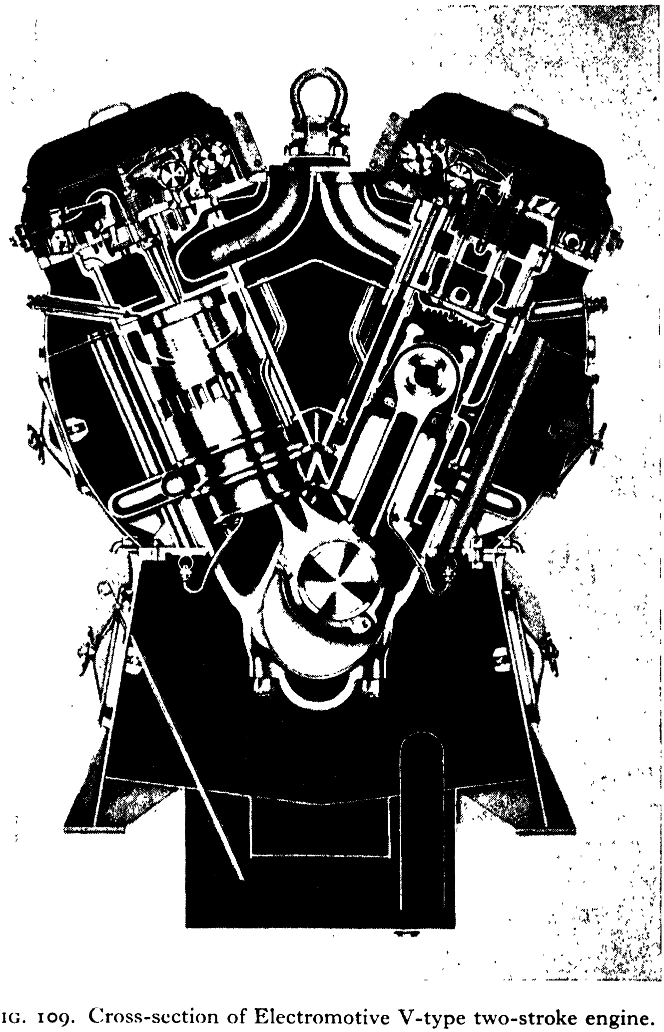


FIG. 109. Cross-section of Electromotive V-type two-stroke engine.

A governor is installed to control the speed of the engine to the setting determined by the throttle position, this latter being operated by mechanical linkage on shunting and similar non-multiple-unit locomotives and by an electro-pneumatic system on

multiple-unit main-line locomotives. This E.P. system comprises four magnet valves and an air-engine, these valves being energised from the throttle cylinder on the master controller which by a variety of combinations enables running speeds of 275, 350, 425, 500, 575, 650, 725, 800 r.p.m. to be obtained. The magnet valves function to admit air to the various cylinders of the air-engine which is connected by linkage to the governor control arm. The governor itself comprises four essential sections: the oil supply, the speed control column, the power piston and the compensating mechanism. Each of these has a definite function in the operation of the hydraulic governor system. The oil supply provides both lubrication and hydraulic power besides being necessary for the loading control system described on page 198. The speed control column, operating under the combined settings of the governor throttle arm and the rotating flyweights, controls the power piston which in turn controls the injector pump setting racks. Any tendency to hunt or fluctuate is damped by the compensating mechanism.

All the air passing into the blowers is drawn through large filters situated one above each blower, these filters consisting of cylindrical perforated metal housings containing filter elements of finely shredded copper held between expanded and perforated metal cylinders. The oiled surface of the shredded copper removes dust and other particles from the air as it passes through.

The Fairbanks-Morse Opposed-Piston Engine: U.S.A. The latest engine to be applied to locomotive operation is the two-stroke opposed-piston engine originally designed in 1935 and used for all kinds of industrial and marine purposes. The underlying principle of this engine is the use of a plain open-ended cylinder containing two pistons between which the combustion takes place, and which in consequence move away from each other under the action of the resulting gases. Towards the end of their outward stroke, these pistons uncover the air inlet and exhaust ports, apertures in the cylinder liner and as a result no valves at all are required.

A longitudinal sectional view of the engine is shown in Fig. 110 in which the main features can be seen. The main structural part of the engine is the cylinder block, fabricated from welded steel plates designed to give the necessary strength and rigidity.

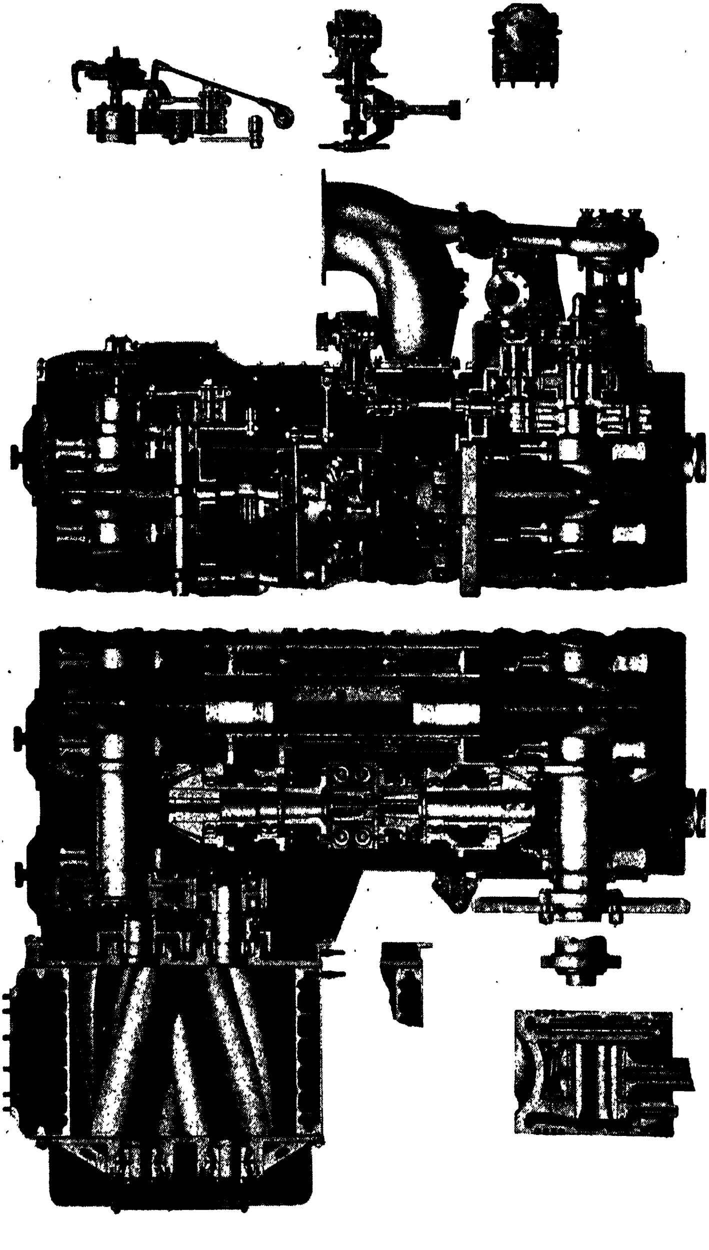
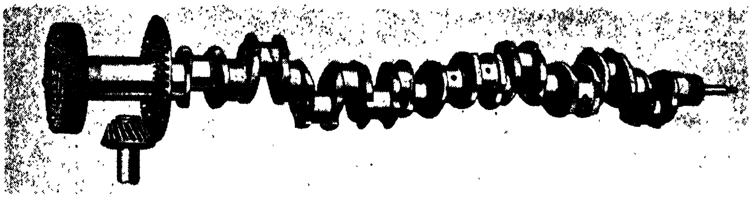
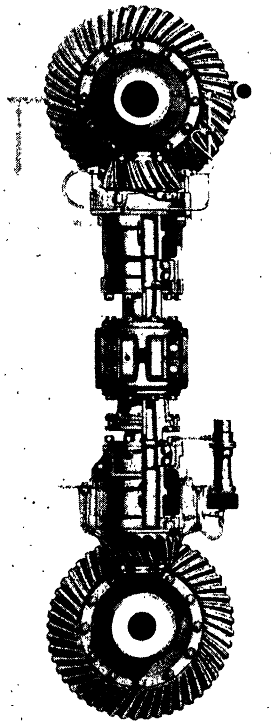


FIG. 110. Longitudinal section two-stroke opposed-piston diesel engine.





Horizontal deck plates are bored to receive the cylinder liners and the side plates are extended to support the blower in line with the upper crankshaft. Suitable compartments and passages are provided for governor gear, vertical drive assembly, upper and lower countershafts, scavenging air, exhaust gases and injector-pump units. A sheet metal cover and oil pan reservoir enclose the upper and lower crankcase compartments respectively and suitable inspection covers complete the closure at the sides. Removable cylinder liners, made of close-grained iron, are bolted into the cylinder block, each liner having rubber sealing rings to isolate the various compartments. Two rows of ports are set in the sides, the upper

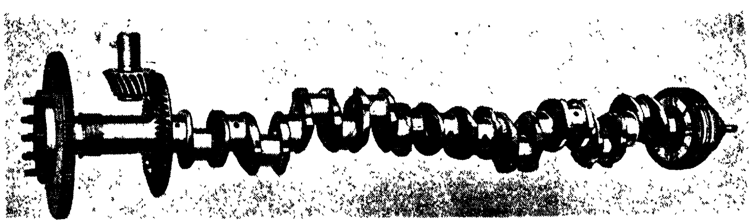


FIG. 111. Crankshafts and vertical drive gear of opposed-piston engine.

for inlet of the scavenging air and the lower layer ones for exhaust. Openings are also provided for the two injection nozzles and a cylinder pressure relief valve.

The upper and lower crankshafts transmit the power developed in the cylinders to the vertical drive gears and crankshaft coupling respectively. Each is made of chrome-nickel-molybdenum alloy with precision-machined bearing surfaces, the upper shaft carrying the blower drive gear and the lower one a torsional damper.

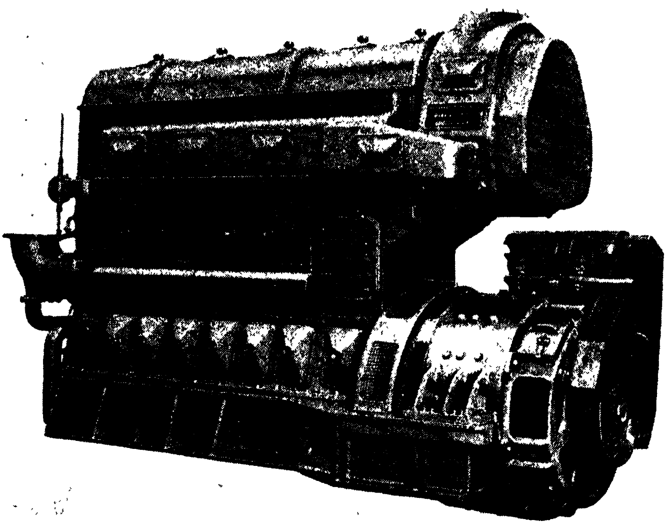


FIG. 112. Fairbanks-Morse 6-cyl. two-stroke opposed-piston engine and generator.

They are supported in plain metal bearings and provided with thrust bearings next to the bevel-drive gears. The vertical shaft connecting the upper and lower crankshafts is made up of three parts : the upper and lower pinion shafts, and the flexible coupling between them. Each pinion shaft runs in a large roller bearing and is further supported by a thrust bearing. The flexible coupling provides torsional flexibility, compensates for expansion and has a timing adjustment to ensure correct relative positioning of the two crankshafts. Fig. 111

shows the upper and lower crankshafts of a ten-cylinder engine, together with the vertical drive assembly.

Two-part pistons are employed, the inner piston-pin bracket being securely bolted to the main piston body as shown in the lower left-hand corner of Fig. 110. Oil for cooling of the pistons is provided by a small passageway up the connecting rod from the crankpin main bearing.

The injection system comprises two injection pumps and two nozzles for each cylinder, located one on each side. Injection pumps are mounted vertically direct under the camshafts and are of the constant-stroke rotating-plunger type, similar to that described earlier. Injection nozzles are spring-loaded and are fitted with a built-in fuel fitter, each nozzle being connected to its pump by short equal lengths of high-pressure tubing. Fig. 112 shows a complete six-cylinder engine-generator set with belt-driven exciter-auxiliary generator unit. The largest engine of this type has ten cylinders, a speed range of 300 to 850 r.p.m. and a maximum output of 2100 h.p.; it weighs 34,000 lbs., giving a power-weight ratio of 16·2 lbs. per b.h.p.

The Sulzer 2200 h.p. Double Bank Engine (Europe). The two engines previously described each have two series of pistons and connecting rods, the former a V-type and the latter with

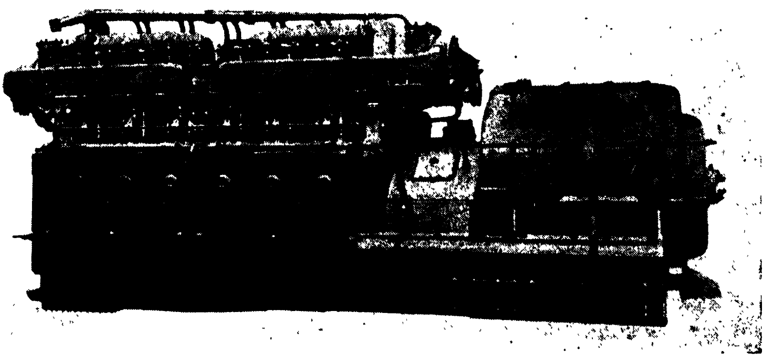


FIG. 113A. Sulzer 12-cyl. four-stroke twin-bank engine.

opposed pistons and two crankshafts. The Sulzer 2200 h.p. engine operates on the four-stroke cycle and has twelve cylinders grouped in two parallel vertical banks of six cylinders, each with

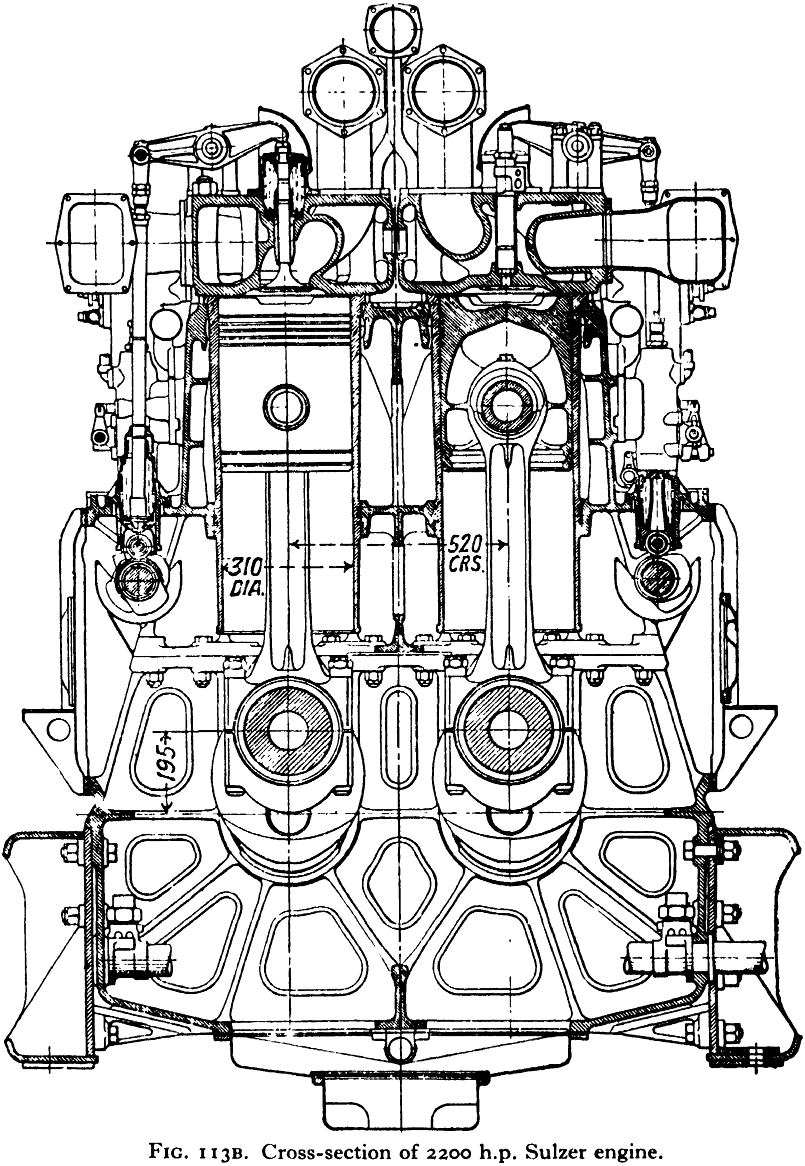


FIG. 113B. Cross-section of 2200 h.p. Sulzer engine.

its own crankshaft. A gear wheel is fitted on each crankshaft and these drive a common pinion on the output shaft with a step-up ratio of 1·2 to 1, so that with the maximum crankshaft speed

of 700 r.p.m. the generator speed is 840 r.p.m. Two Rateau pressure-chargers driven by exhaust gas turbines supply charging air, one to each bank of six cylinders.

A view of the complete engine-generator set appears in Fig. 113A, a cross-sectional drawing in Fig. 113B and the cylinder block, crankcase and crankshafts in Fig. 114.

The crankcase is a steel casting built up of two halves welded together, stiffened by strong webs and carrying all the main bearings fitted into housings. The cylinder block is of steel, also welded from two halves, and is bolted to the crankcase which, in turn, is bolted to a common underframe which supports both

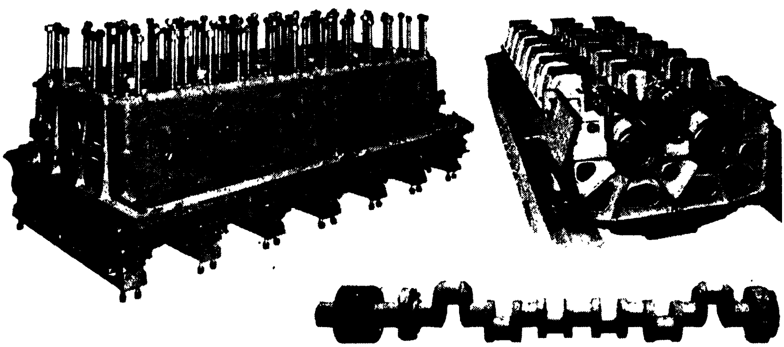


FIG. 114. Cylinder block, crankcase and crankshaft of 2200 h.p. Sulzer engine.

engine and generator. Cylinder liners are of special cast iron, designed to be withdrawn from above, and are supported by a narrow flange with a copper packing ring at the upper end with three rubber rings for sealing purposes at the lower end. Each bank of cylinders has its own camshaft, access to which for maintenance purposes is obtained by a series of doors.

The crankshafts are steel forgings, each carried in seven white-metal-lined bearings; they are fitted with a primary gear-wheel at one end and a torsional oscillation damper at the other. Aluminium alloy pistons are fitted with gudgeon pins and connecting rods of chrome-nickel steel. Each cylinder head is attached separately and has an inlet valve, an exhaust valve, an injector nozzle and an indicator connection.

Separate nozzles and injector pumps of the constant stroke

rotating-plunger type are utilised, one per cylinder. They are controlled from a centrifugal governor which can maintain approximately constant speed at any one of four settings, adjustment of the governor being obtained by alteration of the spring-tension.

The engine, complete with superchargers, etc., weighs approximately 21 tons corresponding to a power/weight ratio of 21·5 lbs. per b.h.p.

M.A.N. 2100 h.p. Double-Bank Engine (Europe). A similar engine to that just described was developed by the well-known German builders of diesel-engines—the Maschinenfabrik-Augs-

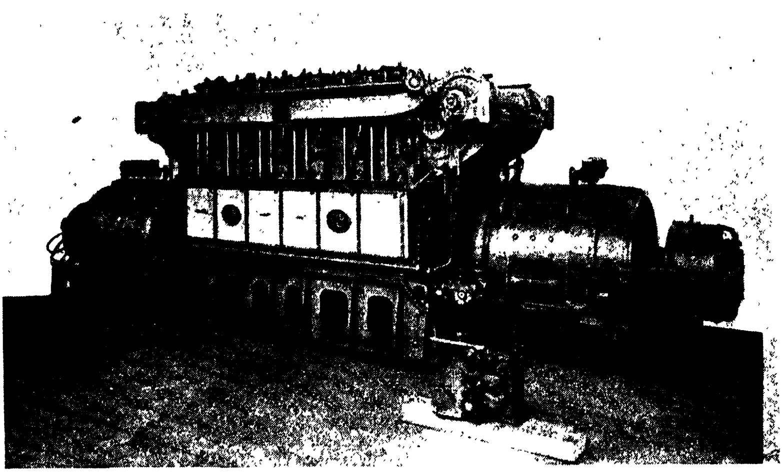


FIG. 115. S.G.C.M.-M.A.N. 2100 h.p. twin engine-generator set.

burg-Nurnberg—for comparative tests with the Sulzer engine on two French main-line locomotives. This engine, which operates on a four-stroke cycle, has two banks of cylinders mounted side by side, but in this case the two crankshafts are entirely independent, each having its own generator, one at each end of the main engine structure. Rateau pressure chargers are employed to give a maximum of 2100 h.p. at 700 r.p.m., with correspondingly lower outputs at the other speeds of 500 and 650 r.p.m. Power/weight ratio for this engine is 14·3 lbs. per b.h.p.

The English Electric Engine (Great Britain). The best-known locomotive design of diesel in this country is the English Electric K-type engine normally used in two models, the six-cylinder developing 350 h.p. and the eight-cylinder developing

465 h.p. Of these, the former has been extensively applied to shunting locomotives in this country, some ninety having been constructed with further machines in construction.

Fig. 116 shows a typical engine-generator set of this type from which it will be seen that a one-piece crankcase carries both the cylinder block and generator, the latter having only one bearing, its armature being direct-coupled to the crankshaft at the engine end. A robust construction has been adopted, the builders'

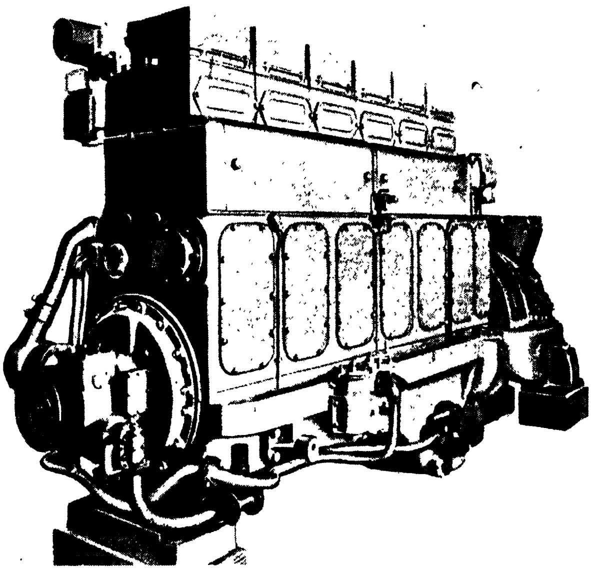


FIG. 116. English Electric 6KT engine-generator set.

principle being the adoption of a reduced power to weight ratio in order to achieve reduction in maintenance.

Regulation of the engine speed may be effected by one of the two following methods :

(*a*) A continuous speed control providing an infinite number of speeds between the minimum of 300 to 350 r.p.m. and the maximum of 680 r.p.m. (*Note* : On certain engines the output can be raised by 10 per cent. by increasing the maximum speed to 750 r.p.m.) This is achieved by a mechanically-operated linkage from the main controller.

(*b*) A fixed speed system, where some four or five nominal speeds only are provided at intervals over the range. The speed is controlled by an electrically-operated governor setting, this arrangement being more suitable for multiple-unit locomotives.

Some interesting new developments have recently been announced by the introduction of V-type engines and superchargers. As a result of this, 12 and 16-cylinder models are now available developing 1200 h.p. and 1600 h.p. respectively at 750 r.p.m. with supercharging.

The Mirrlees TV Engine. A new range of railway oil engines has recently been introduced by the British manufacturer

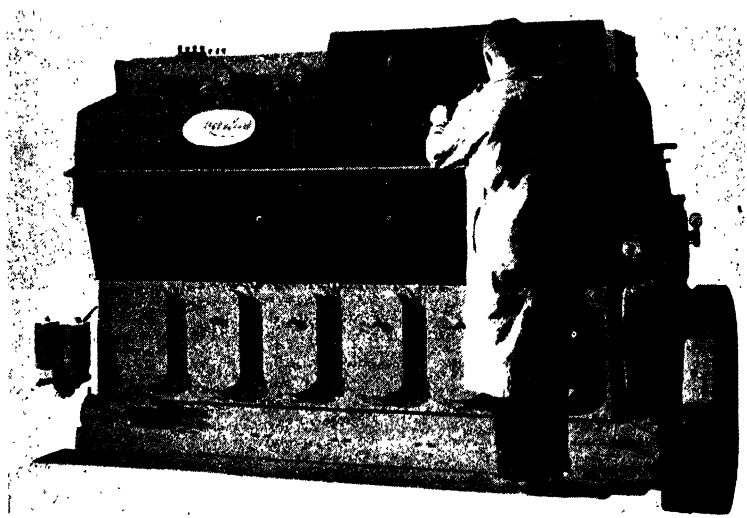
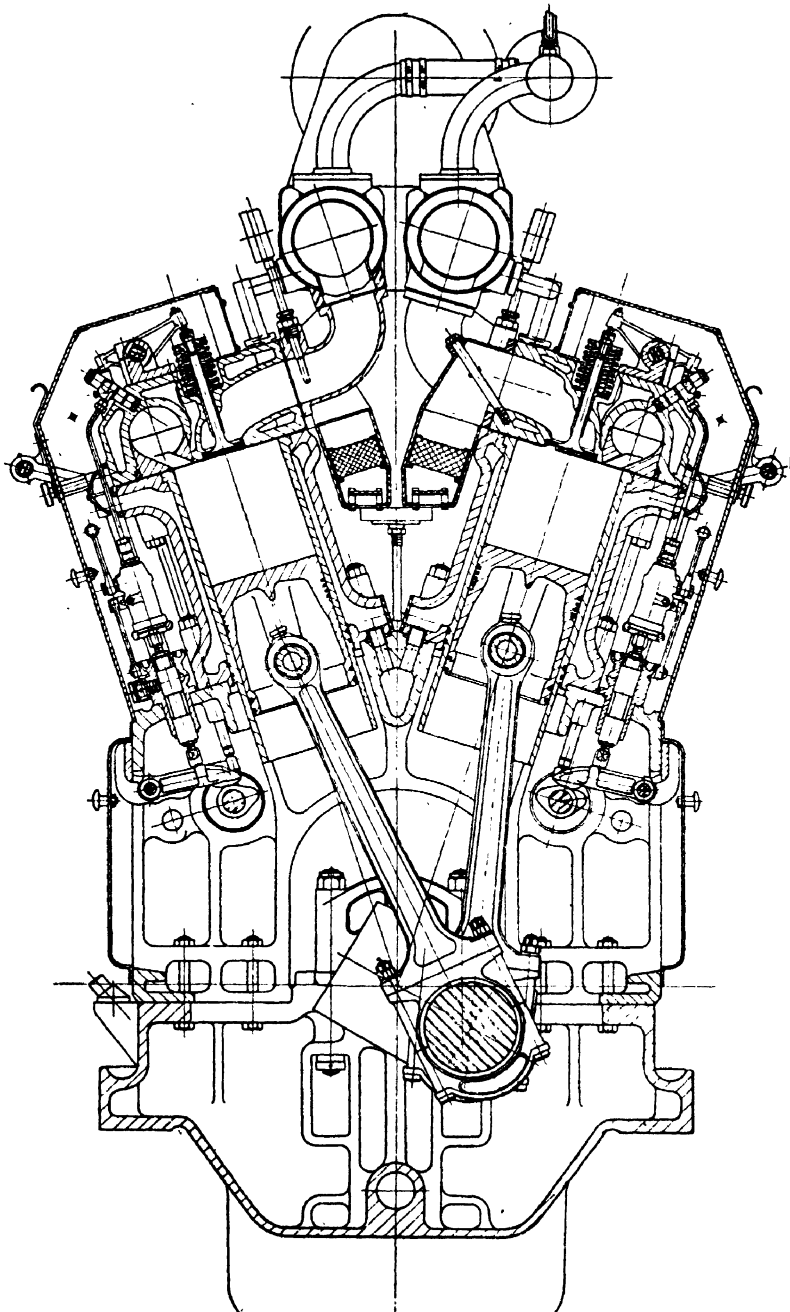


FIG. 117A. 720 h.p. traction diesel engine.

—Mirrlees Bickerton and Day. Three models are available rated at 480, 720 and 960 b.h.p. at 720 r.p.m. with 8, 12 and 16 cylinders respectively (cylinders are $8\frac{1}{2}''$ bore $13\frac{1}{4}''$ stroke). Superchargers can be fitted if desired, these raising the ratings to 700, 1050 and 1400 b.h.p.

The eight-cylinder model has been installed as the power unit in the new diesel-electric shunting and local freight locomotives on the Coras Iompair Eireann (see Appendix, page 355).



The principle material used in construction is cast iron, the engine being built up from bedplate, two crankcase castings, separate cylinder-block castings and individual cylinder heads. Where weight is a dominating factor fabricated construction can be used thereby reducing the total by one-sixth. Sections and a photograph of a 12-cyl. model appear in Fig. 117. Two points are worthy of note: the small angle of 35° separating the two banks of cylinders; and the use of two camshafts, one for each cylinder bank, both gear-driven from the flywheel end.

Other Engines. Illustrations of three other engines appear in Fig. 118. These are as follow:

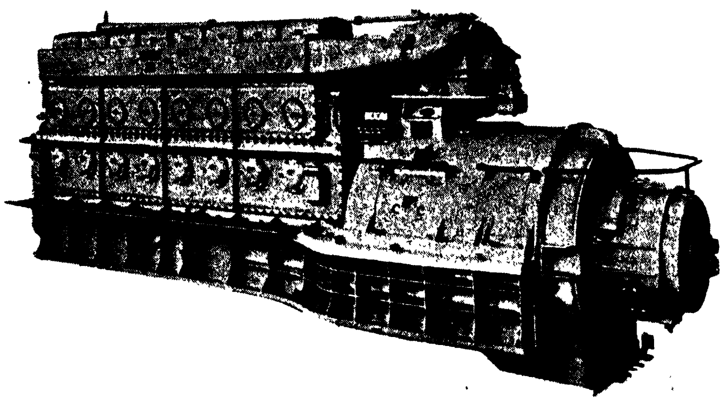
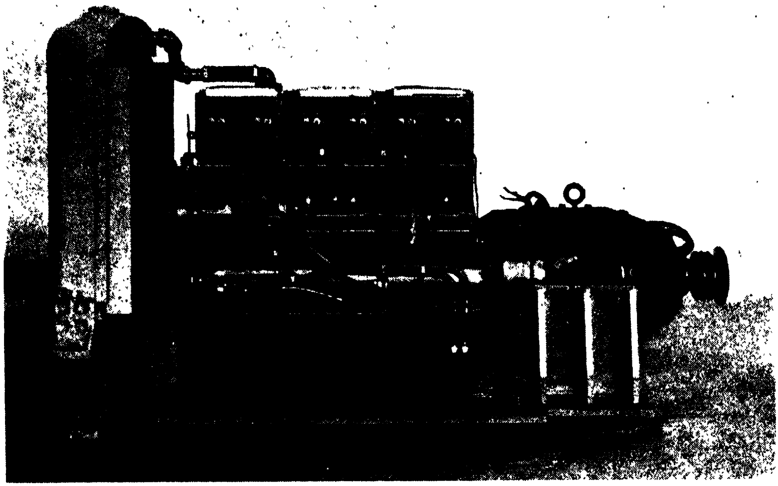


FIG. 118. Typical diesel-engine-generator sets for locomotive purposes. (*a*) Sulzer 1200 h.p. 8-cyl. supercharged engine.

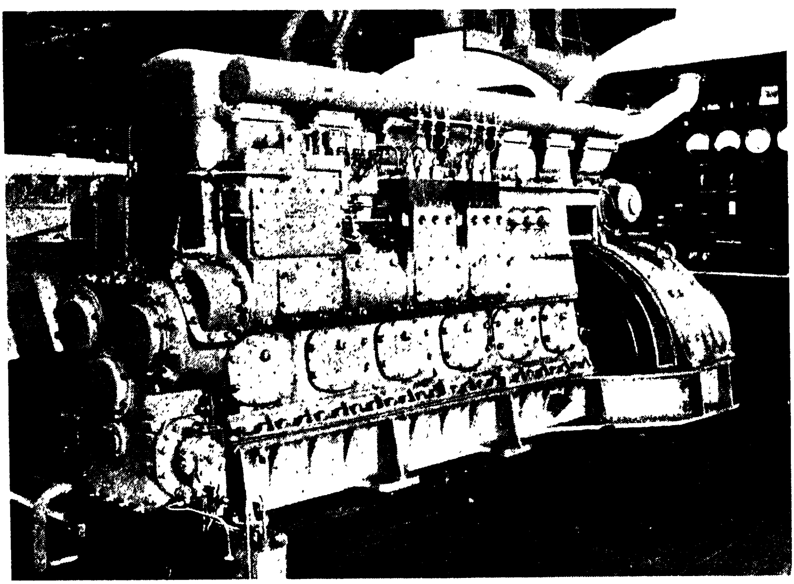
(*a*) Sulzer Brothers eight-cylinder four-stroke supercharged engine developing a maximum output of 1200 h.p. and with a speed range of 460–750 r.p.m.

(*b*) The Cummins 150 h.p. set, which with six cylinders $4\frac{7}{8}''$ bore × 6″ stroke and a speed of 1800 r.p.m. is one of the smallest locomotive diesels built. It is used in certain light-weight narrow-gauge twin-engined shunting locomotives.

(*c*) The Frichs (Denmark) six-cylinder four-stroke engine, developing 455 h.p. at 650 r.p.m., as used in a large number of Danish 1–C_0–1 locomotives. Power/weight ratio is 31·6 lbs. per



(*b*) Cummins 150 h.p. 6-cyl. engine as used on light twin-engined shunting locomotives.



(*c*) Frichs 455 h.p. engine-generator set.

FIG. 118. Typical diesel-engine-generator sets for locomotive purposes.

h.p.: note the increased value of this ratio with non-supercharged four-stroke engines.

Generators and Exciters. To convert the rotational-torque of the diesel-engine into the electrical energy required for supply to the traction-motors, all diesel-engines have a generator direct-coupled to their output shafts. Several of these combined units have been illustrated in the foregoing pages and, in general, the construction of the generators conforms to the following standards.

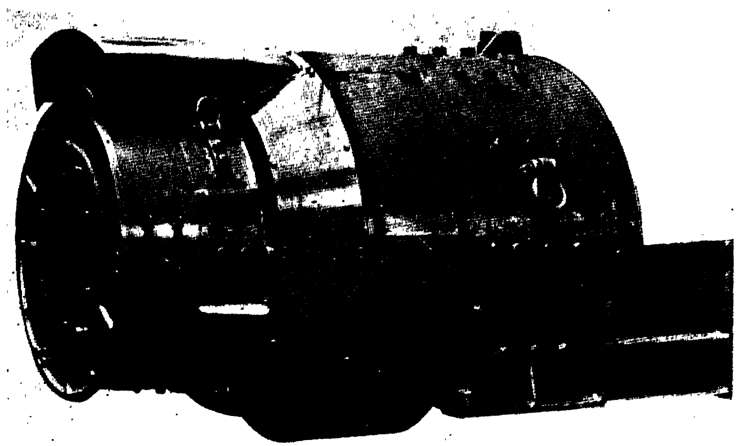


FIG. 119A. Laurence-Scott Electromotors 450 h.p. diesel-electric locomotive generator and overhung exciter.

The frame, usually fabricated from rolled steel but occasionally cast with smaller types, is of ample section for both mechanical and magnetic duties and is supported from the bedplate or crank-case extension, as circumstances require, by side-flanges or feet welded externally. From six to ten main poles, together with their associated interpoles, are bolted to machined faces within the frame and on these are clamped the respective field coils. One or two end-plates are employed to support the armature and brushgear, these being fitted with anti-friction bearings, and frequently the outer end-plate is machined and faced to carry an overhung exciter or auxiliary generator frame.

Armature construction closely follows that of standard D.C. machines with equalised lap windings. Cooling is carried out by

a large fan at the engine end of the armature shaft except in rare cases where an external blower is fitted. Field windings are usually complex with compound or twin-shunt coils together with a special starting winding which enables the generator to function as a battery-driven series motor for starting the engine.

Exciters and auxiliary generators are smaller editions of these main generators except where special characteristics are to be catered for, as outlined under the control schemes. Three

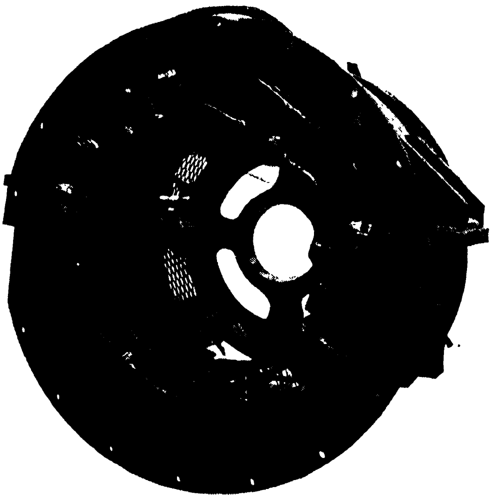


FIG. 119B. Frame with windings of English Electric overhung generator.

methods of mounting and driving these are available. These are :

(*a*) By overhanging the frame and armature from the main-generator end-plate and shaft as in Fig. 119A., the drive in this case coming direct from the engine.

(*b*) By mounting the exciter and/or auxiliary generator externally on the main generator frame and driving through a step-up V-rope and belt pulley system. This method enables these machines to be run at higher speeds than the engine and, consequently, permits a reduction in size and field system (Fig. 112).

(*c*) By utilising a separate auxiliary engine of 50 to 150 h.p. according to the power required, this engine and the auxiliary machines having a separate bedplate.

A typical generator and exciter, and a main generator frame, are shown in Fig. 119.

Engine-Loading. The ideal system of transmission for a diesel-locomotive is one in which the full power of the engine can be utilised by conversion to tractive effort over the whole speed range of the locomotive; i.e. where the generator power output is constant regardless of the current which it is supplying to the traction motors. Fig. 120 shows the fundamental characteristic corresponding to this condition.

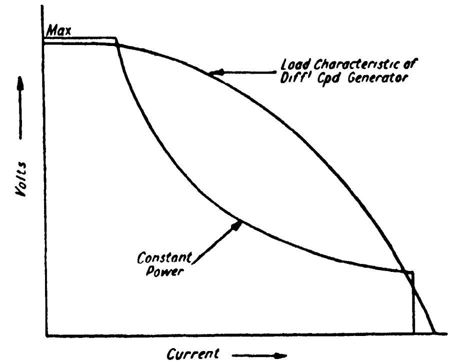


FIG. 120. Constant power characteristic (ideal), and load characteristic of differentially-compounded generator.

With a normal differerentially - compounded generator, i.e. in which the series field acts in opposition to the shunt so tending to decrease output voltage with increasing load, a characteristic of the form labelled in Fig. 120 is obtained. In consequence, a generator of this type is totally unsuitable for diesel-engine loading unless combined with some other form of load supervision. This is due to the following facts:

(*a*) If the generator output characteristic crosses to the upper side of the engine output curve, the generator would in such a case be trying to develop more power than the engine can supply, and this will result in overloading with consequent drop in engine speed and output.

(*b*) Alternatively, if the curves do not intersect, i.e. the generator output curve lies wholly beneath the constant power curve, then the full output of the engine will never be utilised, an uneconomical state of affairs.

All manufacturers have their own individual methods for overcoming this difficulty, all involving some scheme for modification of the generator output. Several of the more important are discussed in the following pages.

Loading Control Schemes

Differential Exciter Control (Westinghouse). This scheme utilises a six-pole exciter with a rather unorthodox arrangement

of field windings. Four poles of this exciter carry a battery-energised shunt winding together with a cumulative (assisting) main generator current series winding. This field system produces a characteristic as shown by curve AA (Fig. 121A). The remaining two poles have self-excited shunt windings and a differential main current series winding, the general connections being as shown in Fig. 121B. As the armature is wave-wound, this two-pole system modifies the AA characteristic as follows: when the shunt ampere-turns equal those of the series, no field is produced and the output is at X. Should the main current decrease, the shunt excitation will predominate, resulting in a

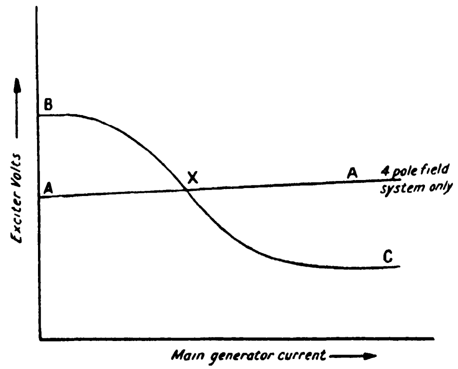


FIG. 121A. Exciter characteristic produced by split-field windings.

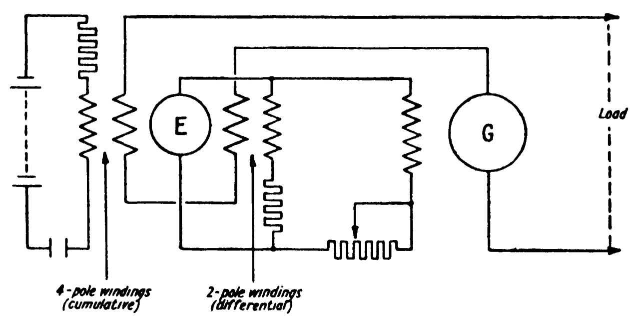


FIG. 121B. Simplified connection diagram—split-field differential exciter.

boosting voltage being applied to curve AA, so producing curve XB as the main current decreases to zero. Vice-versa, increases in main current beyond X produce a predominating reverse series excitation with consequent bucking voltage opposing characteristic AA and depressing it to XC.

When an exciter with this characteristic is used for supplying field current to a simple-shunt main generator, the characteristic

of this latter takes up the shape shown in Fig. 121C where throughout the greater portion of the current range the full engine output is converted into tractive power.

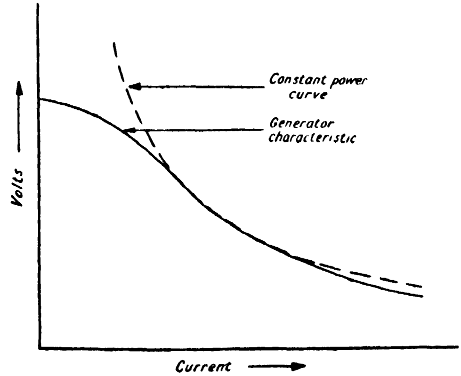


FIG. 121C. Main generator output curve with split-field differential excitation.

Continuous Speed Control (English Electric). (Simple scheme with twin-shunt generator and torque loading control.) The system now in use in the majority of diesel-electric shunting locomotives in service in this country incorporates one or more features of the following general scheme.

The generator has two independent shunt windings, one self-excited and the other separately-excited from a battery or auxiliary generator. By careful design and adjustment the self-field circuit is arranged so that the machine is incapable of building up a voltage on this field alone, but, on the application of a small current to the separately-excited winding, sufficient flux is created to overcome this, resulting in the generator volts rising, the resultant balancing voltage being controlled by the amount of separate field excitation current supplied. This arrangement enables very small battery field currents to be instrumental in providing the large magnetising ampere-turns required with consequent simplification of control gear. As a result of these connections, the generator characteristic is similar to that of a differentially-compounded machine in that increases in main current produce slight depression of the output voltage and, in turn, this reduces the self-field current so that the voltage falls still further until a balance is obtained. When using this type of generator,

acceleration of a locomotive is divided into two distinct stages; first, where the battery field current is progressively raised with minimum engine speed; and, secondly, where the engine speed is steadily raised to its maximum with constant battery field.

The method of load-control incorporates a vibrating contactor in the generator field circuit which operates under the control of the engine governor relay. When the maximum injection position corresponding to full load of the engine is reached, any additional power demands cause the governor, acting through this relay, to open the contactor, an action which inserts resistance into the generator battery-field circuit. This reduces the generator output and hence the load on the engine, so restoring normal conditions

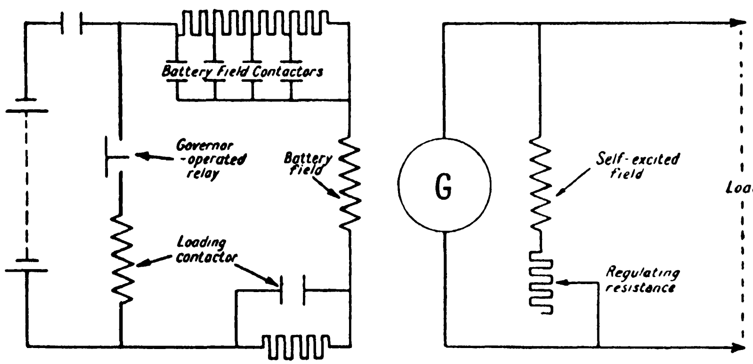


FIG. 122. Twin-shunt generator with torque loading control.

when the contactor again closes. In operation, this results in rapid vibration of the contactor, the timing and operation of which is automatically adjusted by the governor relay to suit the varying current demands whilst protecting the engine against overload. Fig. 122 shows the essential connections for the twin-field generator incorporating this form of load control.

The Simplex-Sécheron Regulator. The basic principle underlying this system utilises a Wheatstone bridge with two set resistance arms, a controller-operated rheostat and an engine governor controlled rheostat (Fig. 123). A 150 volt supply is fed to the bridge network and the armature of a small separately-driven motor is connected across the network, so that any out-of-balance in the two circuits causes this motor to rotate in the appropriate direction. A regulator is connected in the generator

or, alternatively, the exciter field circuit and this motor is used to drive the tapping arm through reduction gearing.

On setting the control handle to any particular operating position, the bridge out-of-balance sets up a potential across the regulator motor and causes it to adjust the main generator excitation until the point is reached where the engine-loading is correct

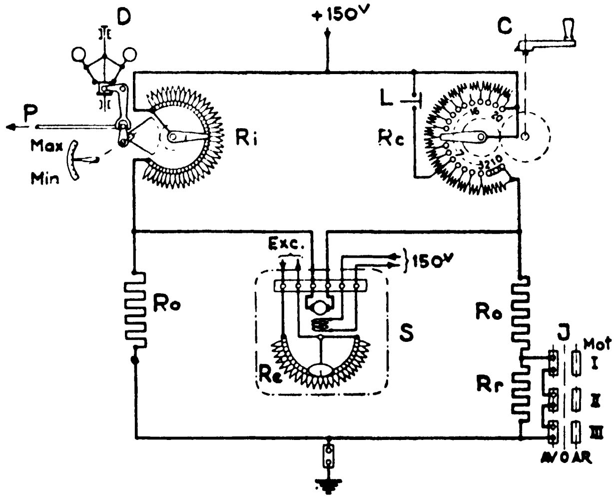


FIG. 123. Basic circuit of Simplex-Sécheron regulator load control.

S. Simplex-Sécheron regulator for main generator excitation control.
R_e. Exciter field regulator.
R_0. Wheatstone bridge fixed resistance tappings.
D. Engine governor.
P. Injector-pump control rod and indicator.
R_1. Governor-controlled regulator.
R_c. Master controller operated regulator.
C. Main control handle.
L. Injection limiter relay (reduces injection when supercharger is out of action).
R_r. Speed reducing resistance (reduces speed to two-thirds in event of a fault on one traction motor).
J. Auxiliary contacts on reverser.

and the governor-operated regulator has consequently acted to balance the network. As the locomotive proceeds, variations in the engine loading cause reactions in the governor regulator setting, resulting in the necessary adjustments being made by the motor-driven regulator to the main generator output.

The Servo Field Regulator (Brown-Boveri). The idea of inserting a governor-controlled load regulator in the generator field circuit has been adopted by a number of concerns on both

sides of the Atlantic. In Europe, the main exponent is the Sulzer-Brown-Boveri development, the servo-field regulator, a system in which the generator field regulator is moved by a rotating piston, operated by oil which is admitted and released by a governor controlled piston-valve. Adjustment of this regulator control mechanism to compensate for the various speeds and outputs desired is achieved by moving the fulcrum pin by plunger-type solenoids.

The complete circuit of a 1200 h.p. Swiss diesel-electric locomotive (see page 235) incorporating this device for load regulation is shown in Fig. 124, the servo-field regulator being item 17. In general, the itemised list of parts is self-explanatory.

Note that the generator has four field windings : a self-excited shunt, a battery-excited shunt, a series decompounding and a starting winding. The single-phase heating generator provides alternating current for train-heating, a necessity, as all Swiss stock is fitted for heating by this means, supply being normally from the electric locomotives.

Electromotive Control System. The large fleet of General Motors locomotives in service in the U.S.A. use the servo-field regulator for load control. Fig. 125 shows the linkage and hydraulic connections between governor, fuel pumps, field regulator and vane-motor. This latter, which is the means of operating the regulator is supplied through a pilot valve whose function is to regulate the flow of engine lubricating oil to the vane motor so as to maintain proper loading of the engine by compensating for variations in battery and auxiliary generator volts, for temperature changes in the windings and for the condition of the engine. The following is an explanation of the operation of this pilot valve.

At the point " A " (Fig. 125), the pilot valve is connected to linkage between the governor control shaft and the injector linkage. This point will remain stationary except when a new demand is made on the engine. Oil under pressure from the engine enters the pilot valve between ports " B " and " C " which, when the pilot valve is balanced, are covered by the lands on the plunger so that no oil flows either to or from the load regulator. When the pilot valve plunger is lowered by the linkage, oil flows through port " C " to the vane motor to increase the horsepower demand on the engine by increasing the generator field excitation. As the

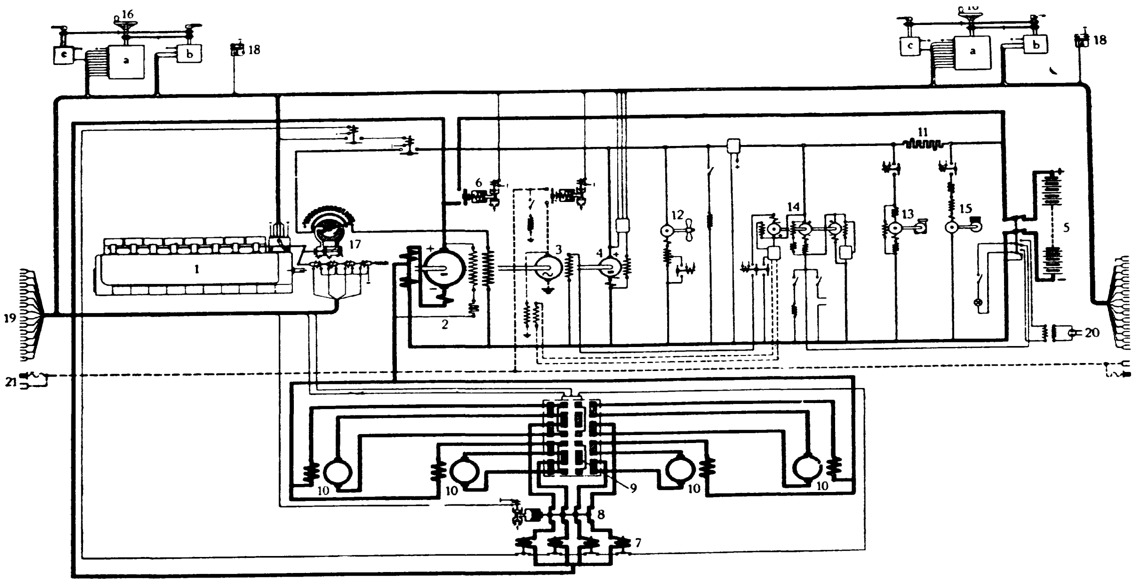


FIG. 124. Complete circuit of 1200 h.p. Swiss locomotive with servo-field regulator loading control.

1. 8-cyl. supercharged engine.
2. Main generator.
3. Single-phase A.C. heating generator.
4. Exciter/auxiliary generator.
5. Main battery.
6. Electro-pneumatic engine starting contactor.
7. Electro-pneumatic heater-circuit contactor.
8. Main motor contactor (electro-pneumatic.
9. Reverser.
10. Traction motors.
11. Charging stability resistance.
12. Radiator fan motor.
13. Cooling waterpump motor.
14. Motor generator set.
    (Left-hand machine is heating generator exciter).
15. Motor compressor set.
16. Master controller.
    (*a*) Main control drum.
    (*b*) Reverser drum.
    (*c*) Starting drum.
17. Servo-field regulator and governor control.
18. Engine stop button.
19. Multiple-way control coupler.
20. Depot lighting plug and transformer.
21. Heater circuit coupler plug and socket.

load increases, the upward movement of the governor power piston is imparted to the pilot valve plunger and this progresses until, when the load on the engine is balanced, ports " B " and " C " are again covered by the lands on the plunger.

To prevent the pilot valve from causing the load regulator to increase the load beyond the balance point, oil returning from the vane-motor through port " B " flows past the cutaway portion of the plunger and through a needle valve to the governor drive

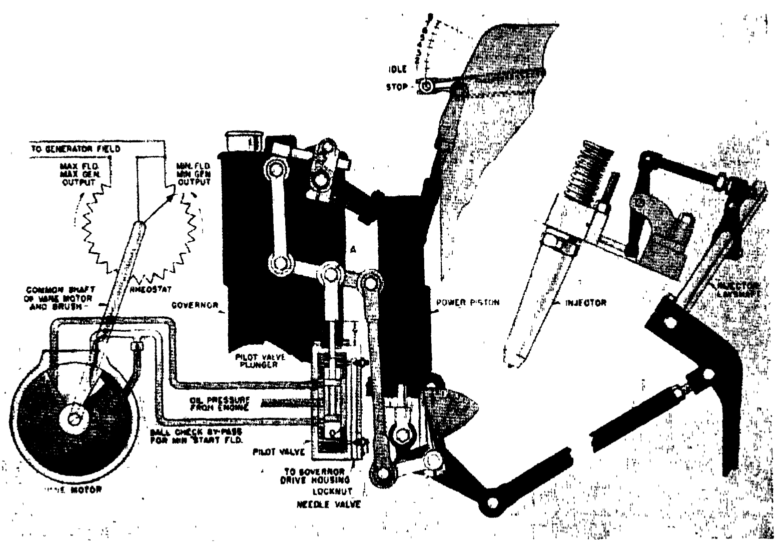


FIG. 125. Linkage between governor and servo field regulator.

housing. The pressure of this oil forces a compensating sleeve to cut off ports " B " and " C " before the pilot valve plunger is returned to its balanced position by the action of the power piston. Adjustment of the needle valves must be carefully carried out, as incorrect setting results in either a sluggish load control or considerable hunting of the engine.

The Axle-Driven Exciter. A rather novel method adopted by the French Jeumont organisation employs a twin shunt field generator in which one portion of the excitation is supplied by a normal engine-driven exciter, its intensity being under the control of the master controller, whilst the second winding is supplied by an axle-driven exciter. This arrangement has the effect of

producing a reduction of generator volts with reduction in speed, which, as series traction motors are employed, corresponds to increases in main current and load.

Speed-Switch Control. Reduced to its simple essentials, the speed-switch scheme comprises a centrifugal switch driven by the engine and arranged that, the faster it is driven, the greater is the percentage of time during which its contacts are closed. When the contacts are closed, the resistance in series with the exciter field is reduced and, in consequence, the exciter volts are at a maximum.

This switch is designed to take up a permanently-closed position when the engine is at full speed and, on any tendency to drop in speed due to overload, it commences to open and consequently reduces the main generator excitation with resultant reduction in the demand on the engine.

Typical Locomotive Wiring Schemes. Fig. 126 shows the circuit diagram of a 2000 h.p. American Locomotive Company—General Electric passenger locomotive (details on page 210). Both a split pole differential exciter and a speed-switch are utilised for load control, the resultant effect of the combination being highly satisfactory.

The equipment comprises two engine-generator sets, each with its own exciter and auxiliary generator, together with four 500 h.p. traction motors. These two sets of equipment operate independently, one circuit comprising a main generator with exciter and auxiliary generator, and two traction motors which can be connected either in series or in parallel with full or shunted field windings. Automatic transition is carried out through the medium of the transfer relay, which functions when conditions are suitable regardless of the engine-speed. The main control handle has eight settings, which control the four electro-pneumatic governor setting valves to give eight running speeds, and on the initial movement of this handle the motor and field connections are first established, after which all control of speed and power is carried out by adjustment of the engine governor. The power contactor chart should assist the reader to follow out the scheme, which is multiple unit to enable these locomotives to operate in groups of two or three units.

Fig. 127 shows the complete wiring circuit of an "A" or driving unit of an Electromotive freight locomotive. The diagram

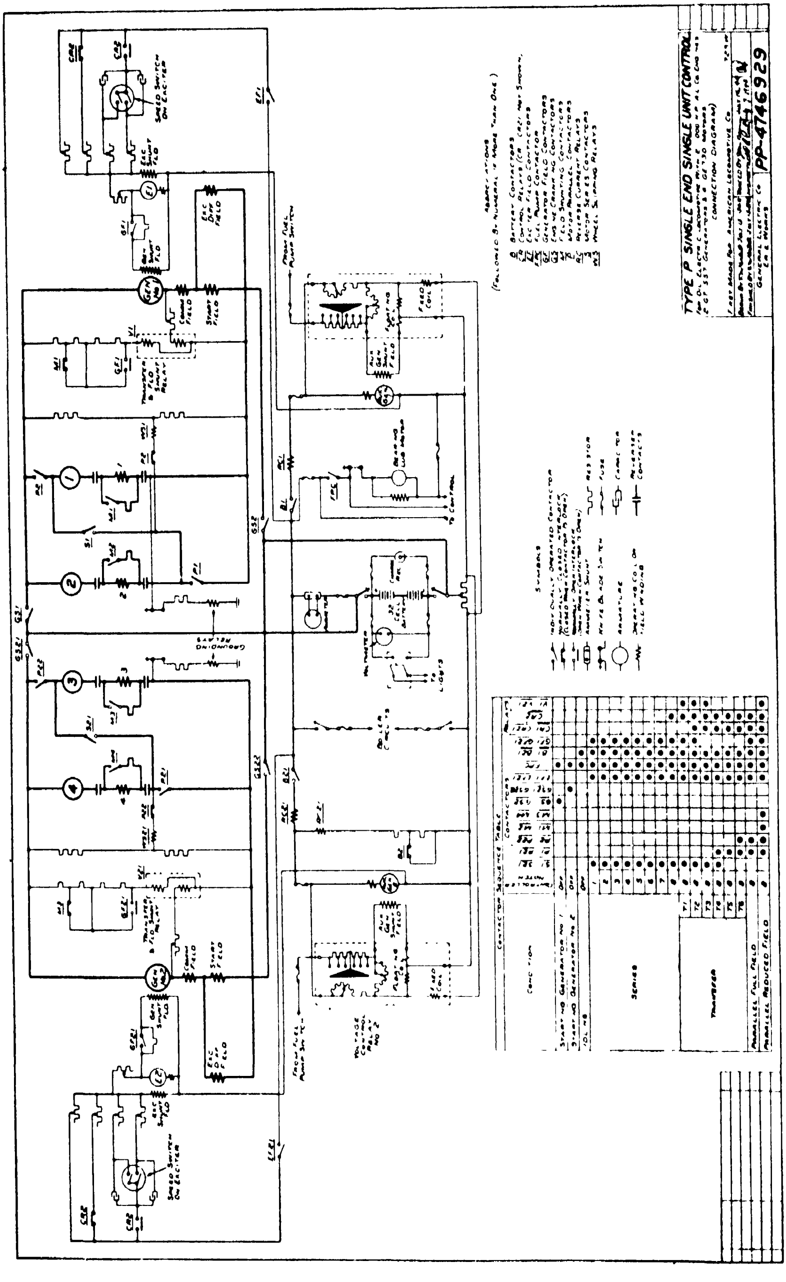


FIG. 126. Alco-G.E. speed switch/differential exciter load control as applied to 2000 h.p. passenger locomotive.

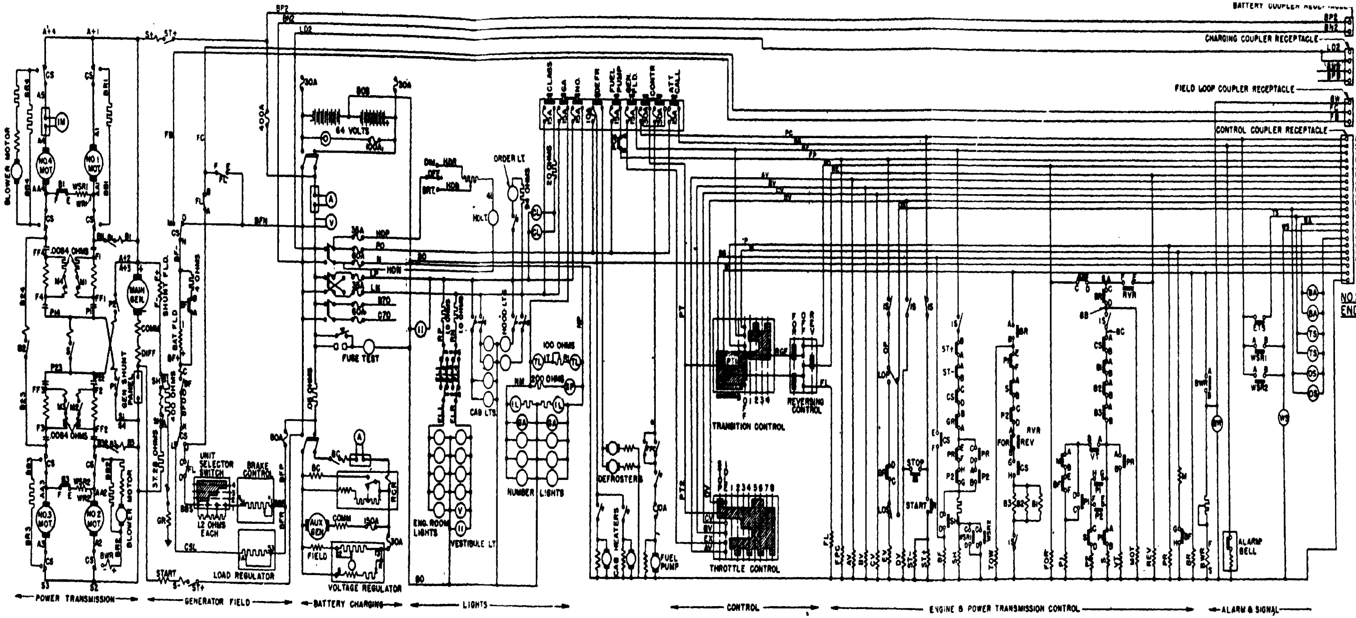


FIG. 127. Complete diagram of a driving unit for an Electromotive freight locomotive.

is exactly as supplied by the manufacturer, as a result of which certain differences in the symbols used will be noticed. One engine-generator set supplies the four traction motors, four operating combinations of which are available. These are :

(1) Two parallel circuits each with two motors in series and employing full field excitation.

(2) The same, but with the motor fields shunted by resistances.

(3) All four motors in parallel with full field.

(4) All four motors in parallel with shunted fields.

Rheostatic braking arrangements are incorporated in the circuit during the operation of which each motor is loaded on to a separate

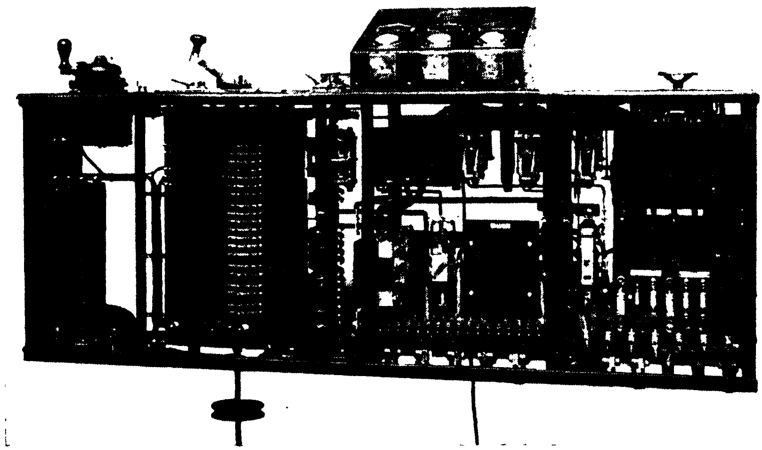


FIG. 128 (i). Examples of mounting of equipment in cubicles.

braking resistance, the four resistances being cooled by two motor-blower sets connected in parallel with two of the brake resistances. Excitation for braking is supplied from the main generator and controlled by varying the generator excitation. The main controller has three handles : the throttle control, giving one idling and eight running speeds, and also controlling the main motor and field contactors ; the transition control, which selects the motor combination and also controls the braking effort ; and the reverser control. Load control is by servo-field regulator, as outlined on page 198. The scheme is arranged with train line and couplers for multiple-unit operation with up to four

units together, in which case two driving " A " units and two non-driving " B " units make up the formation. A " B " unit diagram is identical with that shown in Fig. 127 except that the master controller is omitted.

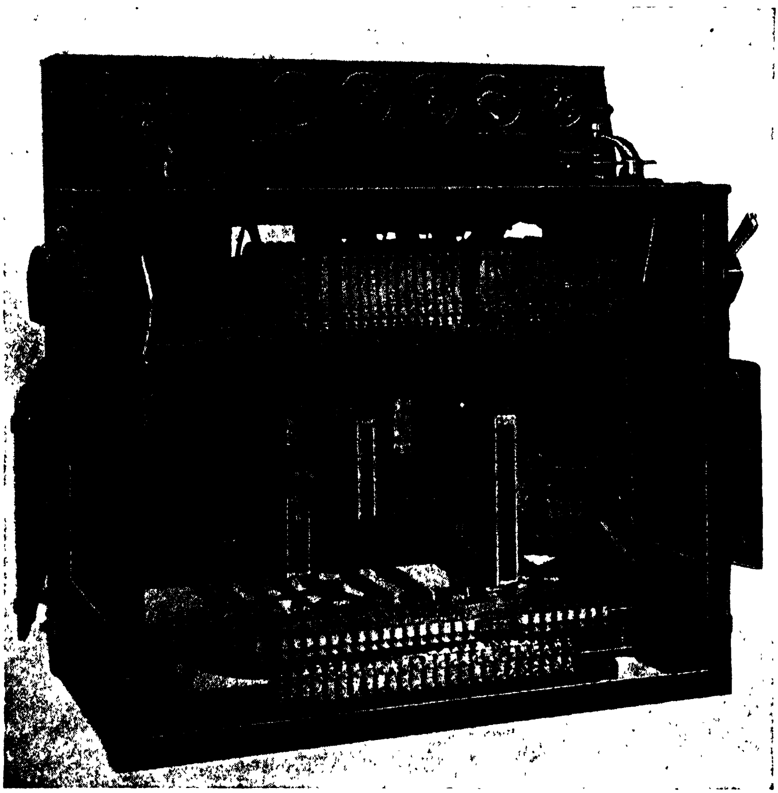


FIG. 128 (ii). Examples of mounting of equipment in cubicles.

Control Gear. In general, control equipment for diesel-electric locomotives is very similar to that employed on normal direct current locomotives. Most manufacturers favour the grouping together of the apparatus either in compartments situated in the interior of the locomotive or in a large cubicle housing controller, reverser and other equipment. Examples of these appear in Fig. 128 and further instances may be seen in the following chapter describing the locomotives themselves.

CHAPTER NINE

DIESEL-ELECTRIC LOCOMOTIVES

As mentioned earlier, the only country which has adopted diesel-electric motive power for all purposes on a large scale is the U.S.A. and in the authors' opinion comprise more than five-sixths of the total number of such locomotives in service throughout the world. It will, therefore, be appreciated that a considerable proportion of the locomotives described in the following pages necessarily are of U.S. manufacture, but, as far as possible, a wide selection of European-built machines has been included.

For reference purposes a list of those to be described or outlined now follows :

U.S.A. :

- Electromotive 4000 h.p. passenger locomotive.
- Alco-G.E. 2000 h.p. mixed-traffic locomotive.
- Electromotive 5400 h.p. four-unit fast freight locomotive.
- Baldwin Westinghouse 3000 h.p. single-unit locomotive.
- Alco-G.E. 1000 h.p. mixed-traffic locomotive.
- Electromotive 660 h.p. shunting locomotive.
- Fairbanks-Morse 1000 h.p. and 6000 h.p. machines.
- Baldwin 2000 h.p. freight and shunting locomotive.
- The Whitcomb and Porter ranges of central cab twin-engined locomotives.
- The 40 ton general-purpose shunting locomotive.

EUROPE :

- The two French 4000 h.p. express passenger locomotives
- 4400 h.p. mixed-traffic locomotive—Roumania.
- 1200 h.p. branch line locomotive—Switzerland.
- 450 h.p. mixed-traffic locomotive—Denmark.
- Shunting locomotives in France and Britain.

NORTH AFRICA :

- 750 h.p. narrow-gauge locomotive.

BRAZIL :

- 500 h.p. mixed-traffic locomotive.

Electromotive 4000 h.p. Passenger Locomotive. Fig. 129 shows a twin-unit 4000 h.p. locomotive of the Chicago and North

Western Railroad, made up of two identical 2000 h.p. sections coupled back to back. Standard U.S. practice in the construction of all main-line passenger locomotives is to build them up from one, two or three such sections with driving cabs fitted where required. Driving units are classified "A", non-driving units "B", each of these types being arranged to operate in multiple unit, controlled from the cab in the leading section. Where the locomotive is required to operate continuously in either direction, two " A " units are utilised (Fig. 129) ; otherwise an " A " and a " B " unit are employed, as in the Santa Fé locomotive in Fig. 130.

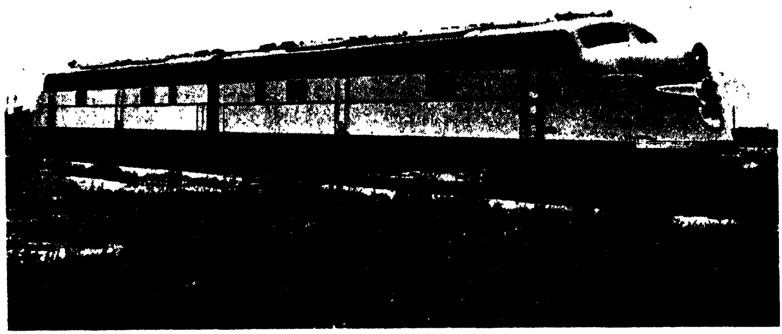


FIG. 129. 4000 h.p. twin-unit passenger locomotive.

Two six-wheel truck assemblies are provided per locomotive unit, interchangeable except for the journal boxes which drive governor and speedometer. The frame is supported by twin-group coil springs which ride on four equalisers carried between the journals. The spring bolster is supported by full elliptical springs, these springs being attached to each end of two spring-planks carried by swing hangers pivoted outside the truck frame. Each truck carries two traction motors geared direct to the outer axles and carried in conventional manner between the driving axles and the bogie transome. The centre axle is idle and is only necessary for braking and load-carrying purposes, the laden weight being equally divided between the three axles of each truck. Clean air is forced to the motors by engine-driven blowers

located in the engine-room and directed thereto through ducts in the body and bolster centre plate, being passed from body to bolster through a hollow main swivel-joint sealed by a sliding

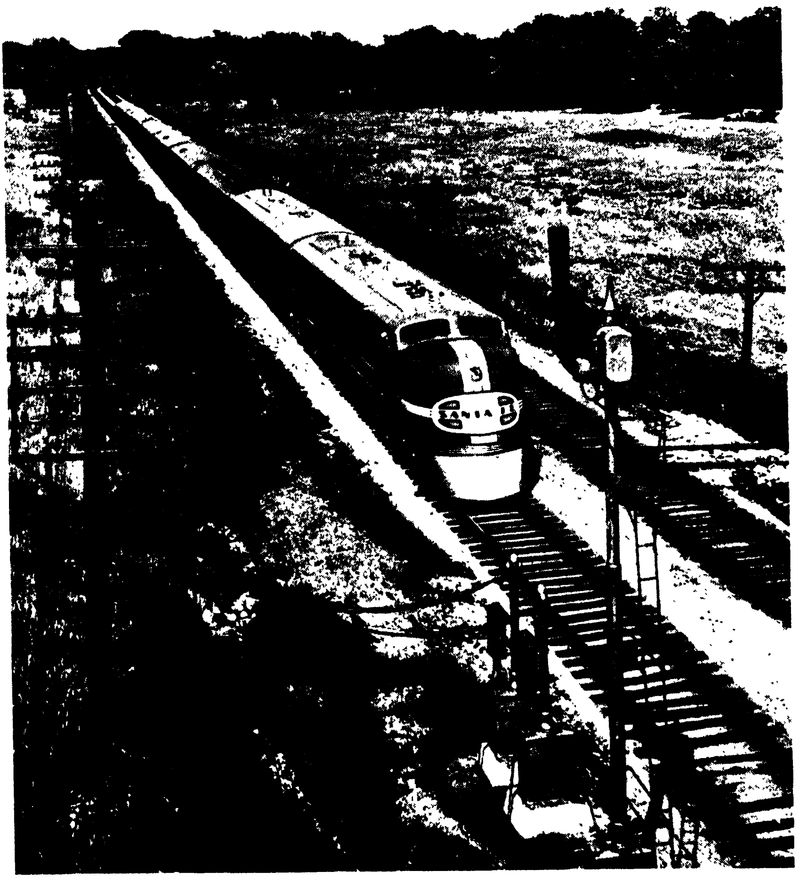


FIG. 130. The " El Capitan " of the Atchison Topeka and Santa Fé Railroad. (This train is powered by an Electromotive 4000 h.p. locomotive.)

steel plate and special gasket. Flexible rubber ducts carry the air from the bogie to the motor intake opening. Four brake cylinders are provided on each truck, these being fitted with automatic slack adjustment. Roller bearings are used on all

axles and on many of these locomotives have attachments to assist in the operation of the following features :

(*a*) Each bearing has a thermocouple indicating device which lights a signal lamp in the driving cab, should that bearing become overheated.

(*b*) A Westinghouse differential braking relay is mounted in the cab, which limits the braking ratio and force to the maximum possible according to the speed.

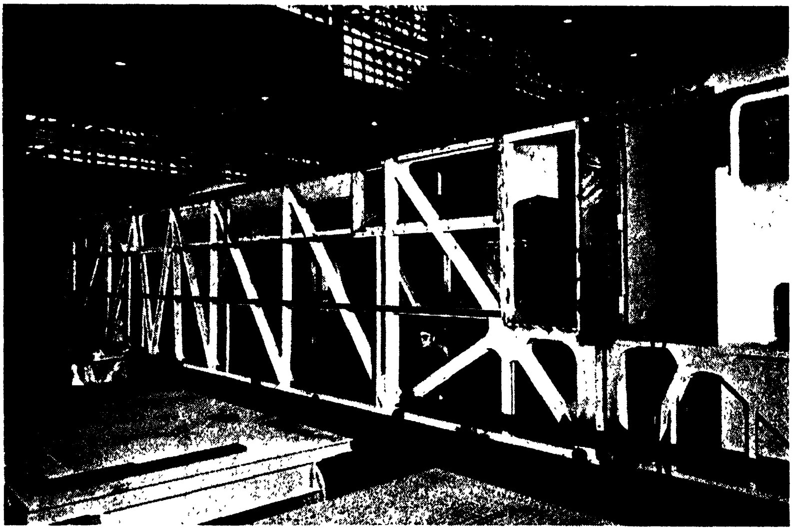


FIG. 131A. Truss framework under construction.

(*c*) By the combination of two features in which the trucks are limited in their displacement relative to the main body, and the axleboxes are fitted with a special flange, the trucks are prevented from slewing away from the track in the event of derailment.

The main body framework is designed in the form of a truss capable of carrying the weight of all the equipment, this latter being supported principally on cross-members extending the full width of the underframe. Rolled steel sections are adopted to ensure straightness and substantial arches are provided to take care of lateral forces or uneven jacking conditions. At the cab end of the " A " unit, special collision framing is provided above the platform, comprising a combination of posts, plates and braces. As will be seen from the photographs, the driving cab is situated

approximately over the leading bogie bolster and is elevated above the locomotive deck level to provide maximum visibility. It is entered from the engine room by a door and four steps. The exterior is covered by plywood panels to which is attached suitable

FIG. 131B. Engine-room of 2000 h.p. locomotive.

gauge steel sheets, an arrangement producing a minimum of weight. Suitable detachable covers and openings are provided in the roof to permit removal of the engine generator sets.

Fig. 131 shows the truss framework of a locomotive in course of construction and an interior view of an engine room.

The motive power of each unit is derived from two independent diesel-generator sets of 1000 h.p. each, each consisting essentially

of one General Motors 12-cylinder V two-stroke engine with scavenging blower, 600 volt generator with servo-field regulator and an auxiliary generator mounted above and driven by V-belts from the main generator. Two traction motors are provided per power plant, these being ventilated by blowers chain-driven from the engine shaft and designed to supply up to 1800 cu. ft. per minute to each motor. Automatic forward transition of motor connections is provided between series parallel and parallel-shunt. Backward transition is automatic from parallel-shunt to parallel and manual from parallel to series. The engines are started in turn by motoring their respective generators from the locomotive battery. All the control-gear is housed in suitably ventilated cabinets, the general layout of the equipment being similar to that of the locomotive shown in Fig. 132.

Each engine has two exhaust manifolds whose outlets extend slightly above the roof line. Two separate cooling systems are provided, each with an engine-driven water pump, fin tube radiators and individual 150 gallon supply tanks. Forced air circulation up to 60,000 cu. ft. per minute per radiator is employed, delivery being controlled by manually-operated shutters mounted in the air-ducts. Provision is made for steam-jet heating of the cooling water after stationary periods in depot, shops, etc.

A Clarkson oil-fired heating boiler is provided at the rear of each unit, complete with feed-water pump, automatic ignition and associated control gear. (For further details refer to Appendix, page 343.)

Alco-G.E. 2000 h.p. Mixed-Traffic Locomotive. Fig. 132A shows a plan and elevation of an American Locomotive Company-General Electric diesel locomotive, as supplied to the New York, New Haven and Hartford Railroad for express passenger and fast freight service. Geared for a maximum speed of 80 m.p.h., the locomotives, operating singly or in pairs, handle the more important through trains over the 157 miles from New Haven to Boston, a route where speed restrictions for curves, etc., are numerous.

In general, the construction and equipment are very similar to the Electromotive 2000 h.p. unit. There are two six-cylinder four-stroke supercharged engines, each developing 1000 h.p., together with two main generators, two auxiliary generators, two exciters and four traction motors. Load control is by the combined action of split-pole differential exciters with speed-

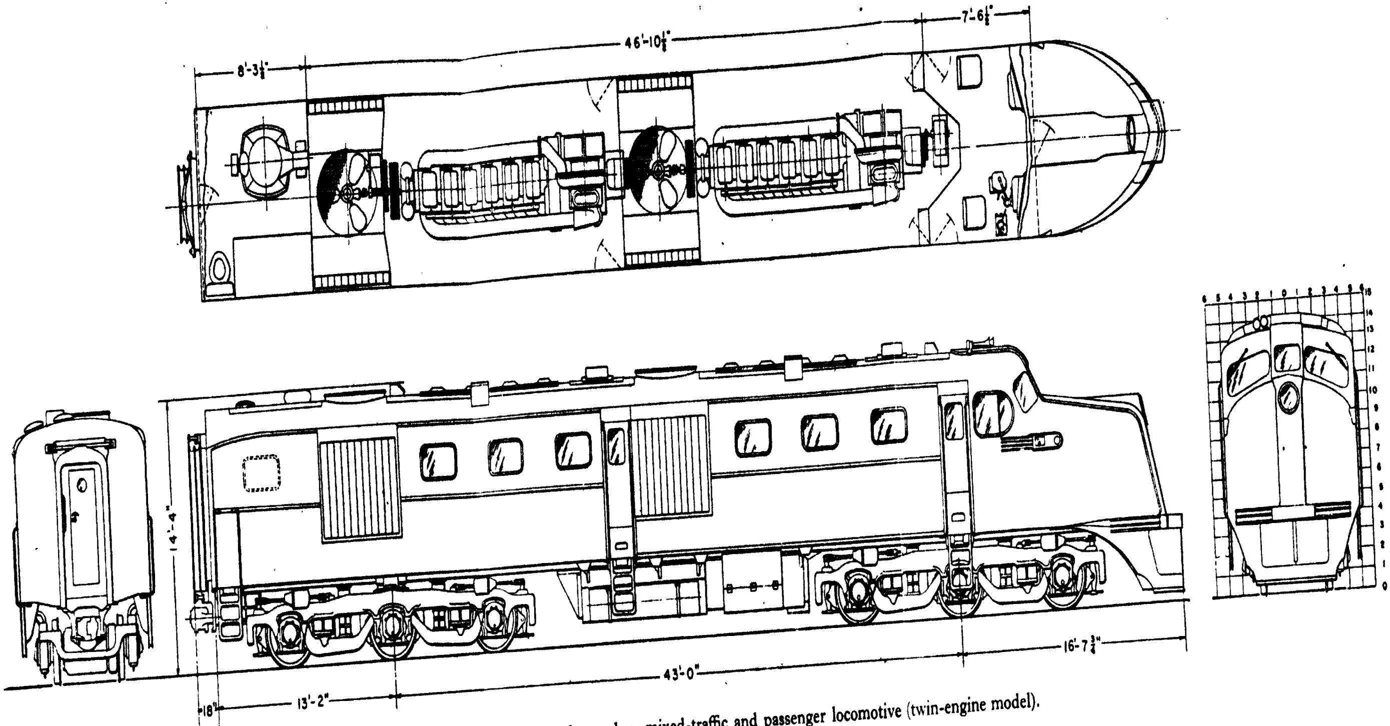


FIG. 132A. Plan and elevation of 2000 h.p. mixed-traffic and passenger locomotive (twin-engine model).

switches, the simplified diagram being as shown in Fig. 126. One-piece steel castings are utilised for the main bogies, each of which is fitted with three axles supported in roller bearings and carries two traction motors arranged to drive the outer axles. Complete statistics are given on page 339.

Fig. 132B shows one unit of the latest locomotive of this type from Alco-G.E. Built for high-speed long-distance traffic on the Atchison Topeka and Santa Fé Railroad each unit is powered by one 16-cylinder supercharged engine.

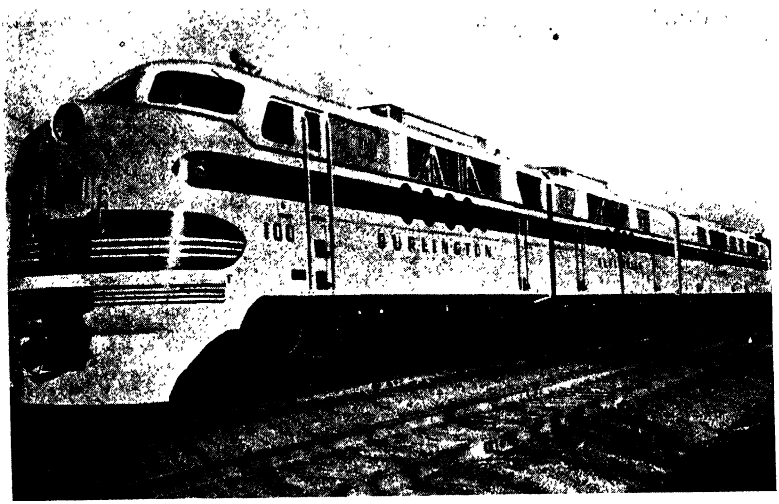


FIG. 133 (i). Electromotive four-unit fast-freight diesel-electric locomotive.

Electromotive 5400 h.p. Fast Freight Locomotive. The locomotive which has become the best-known for its astounding efforts during the recent war is undoubtedly the Electromotive freight locomotive. With its maximum tractive effort of almost 100 tons, the loads hauled, running times achieved and availability for traffic made railway history. It is multiplying in number rapidly and an improved model has recently been introduced which develops 6000 h.p. A head-on view appears in the frontispiece and a complete four-unit locomotive with plan and elevation of one-unit is shown in Fig. 133. Refer to Appendix for leading dimensions, etc., pages 343 and 354.

It will be seen that the locomotive is built up from two identical

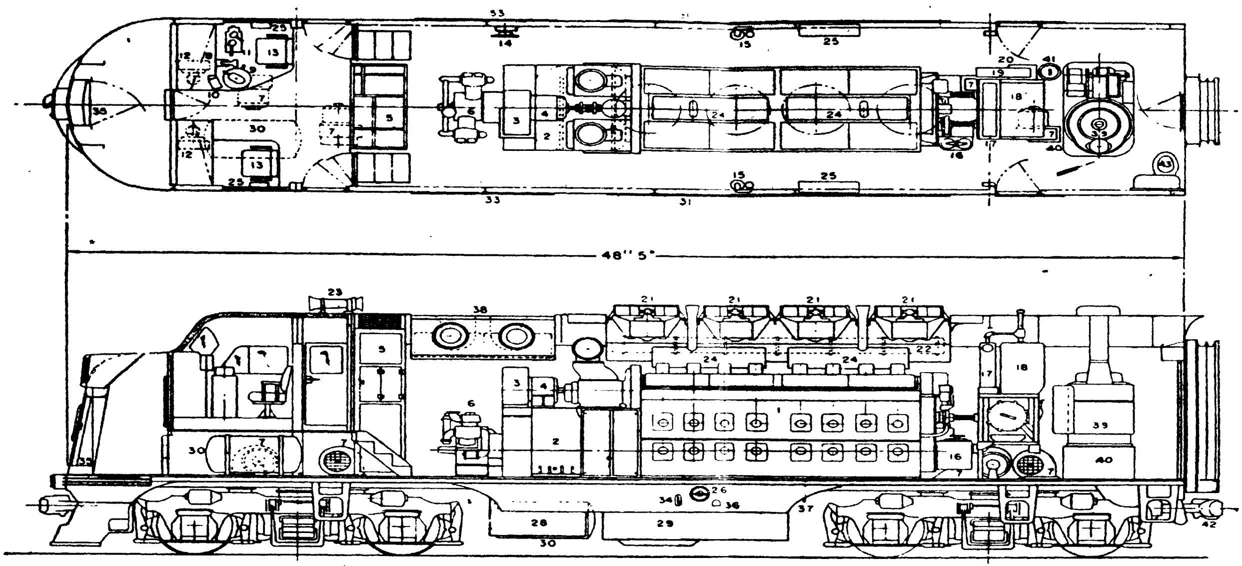


Fig. 133 (ii). Electromotive four-unit fast-freight diesel-electric locomotive.

1. 16-cylinder two-stroke engine.
2. Main generator.
3. Generator blower.
4. Auxiliary generator.
5. Control cubicle.
6. Compressor.
7. Traction-motor blower.
8. Instrument panel.
9. Driving position.
10. Speedometer.
11. Brake valve.
12. Cab heater.
13. Driver's seat.
14. Hand-brake.
15. Fuel-tank ventilator.
16. Lubricating-oil filter.
17. Lubricating-oil cooler.
18. Cooling water tank.
19. Engine control and instrument panel.
20. Servo-field regulator.
21. Motor-fan.
22. Radiator.
23. Horn.
24. Exhaust manifold.
25. Sandbox.
26. Fuel oil filler.
27. Headlight.
28. Batteries.
29. Fuel tank.
30. Air reservoir.
31. Air intake.
32. Heating boiler water intake.
33. Engine-room air intake.
34. Fuel-tank gauge.
35. Door.
36. Emergency fuel stop-valve.
37. Cooling-water filler.
38. Dynamic braking resistances and cooling fans.
39. Train-heating boiler.
40. Boiler water tank.
41. Water-softener.
42. Automatic coupling.
43. Toilet.

sections, each comprising two close-coupled 1350 h.p. units, i.e. an " A " or driving unit and a " B " or booster unit, the whole arranged for multiple-unit operation from the leading cab. 1350, 2700 and 4050 h.p. locomotives are also available by elimination of the requisite units. The general appearance and mode of construction is very similar to that of the same manufacturers' passenger locomotive, except that, being less in output, each unit has only one engine, a 16-cylinder V two-stroke model. The

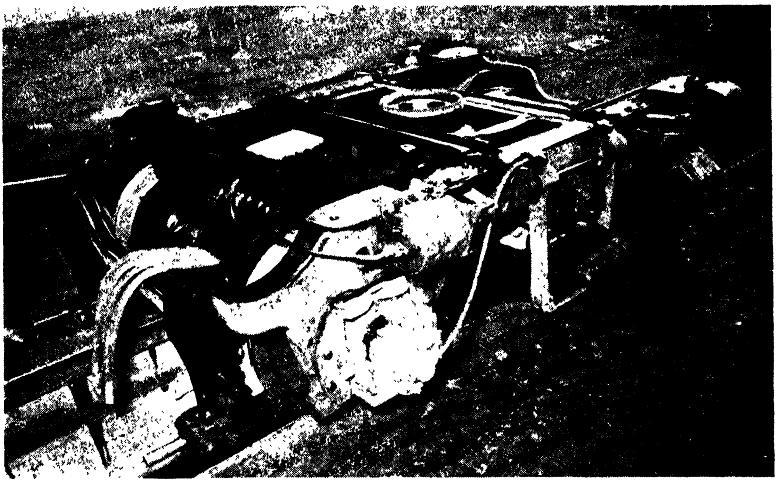


FIG. 134A. Freight locomotive main bogie.

other equipment comprises a direct-coupled main generator ; two traction motor blowers, auxiliary generator and compressor belt-driven from the engine, and four traction motors. These latter, each pair of which is connected permanently in parallel, can be grouped in four combinations, i.e. series full field, series-shunt field, parallel-full field and parallel-shunt field. Rheostatic braking is also incorporated. The circuits of an " A " (driving) unit were shown in Fig. 127.

Two four-wheeled bogies support the main underframe, these being generally similar to the three axle passenger locomotive truck, but have a reduced wheel-base and no carrying axle.

Fig. 134 shows a typical freight locomotive bogie. Note the large hollow swivel pin through which passes the motor ventilating air. Also shown is a view into the electrical equipment compartment.

FIG. 134B. Electrical equipment compartment.

Baldwin 3000 h.p. Single-Unit Locomotive. A new stage in the evolution of the diesel-electric locomotive has been reached by the introduction of the single-unit 3000 h.p. locomotive shown in Fig. 135. Built by the Baldwin Locomotive Works and the Westinghouse Electric Corporation for the Seaboard Air-line Railway, it is intended for haulage of fast fruit and vegetable traffic between Florida and the North-Eastern U.S. cities.

The type of running gear adopted differs from previous diesel-locomotive practice in that it is similar to that used on the large U.S. electric locomotives such as the Pennsylvania GG1 and New Haven units described in Chapter Seven. It comprises two articulated main trucks each with four driving axles and a four-

wheel carrying bogie at the outer end, the wheel arrangement being, in consequence, $2\text{–}D_0 + D_0\text{–}2$, making possible the following weight distribution : 18·2 tons per axle on the leading bogie, 183 tons adhesive on the main driving axles and 19·1 tons per axle on the trailing truck. One-piece steel castings are used with side frames, cross-ties, pedestals, truck centre-pins, cab supports, motor suspensions and equilisation equipment cast integrally. The two trucks are connected together by an articulated joint of

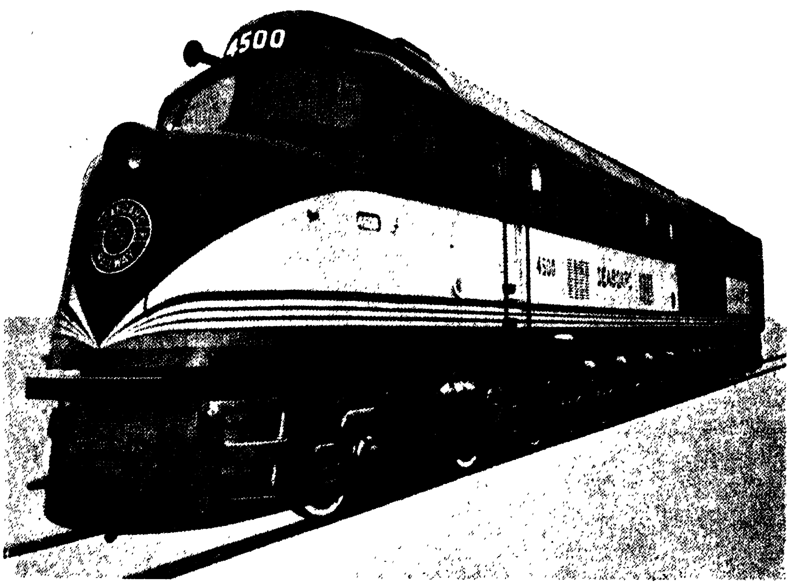


FIG. 135. Baldwin-Westinghouse 3000 h.p. locomotive.

the ball socket and pin type and carry the standard buck-eye couplers at their outer ends, the leading coupler being retractable to improve the streamline effect. All twelve axles are supported in roller bearings, three-point suspension being used on each truck, and the unusual arrangement where both driving and carrying wheels are 40″ in diameter should be noted. Eight axle-hung traction motors of the six-pole forced-ventilated series type are divided equally between the two trucks and possess an unusually large horse-power capacity reserve enabling full-engine output to be used up to 72 m.p.h. Capable of 117 m.p.h., the locomotive is at present restricted to 85 m.p.h.

The underframe is an electrically-welded structure built of steel plates and shapings with a truss support and has the battery compartments, fuel oil and water tanks built integrally. It is carried by the main bogies, the rear pivot being flexible, and supports the engine and radiator compartments, superstructure, etc. At the leading end of the superstructure is the conventional nose and high-level driving cab; next, comes No. 1 engine compartment; then, the main radiator compartment, No. 2 engine compartment and, at the rear, the heating boiler with its auxiliaries. Sheet metal, suitably braced, is used for the upper casing and is sound-insulated and louvre-ventilated where necessary.

Two Baldwin four-stroke eight-cylinder in-line engines, equipped with Elliott-Buchi turbo-chargers, each developing 1500 h.p. at 625 r.p.m., provide the motive-power. A welded steel bedplate structure supports each engine and main generator, the two latter being twelve-pole single-bearing self-ventilated machines with belt-driven combined differential-exciter-auxiliary generator sets mounted on top of their frames. The differential exciters function to control the electrical loading so that it matches the output of the diesel-engine at all speeds and under all conditions. The four motors on each truck are permanently connected to one generator in a series-parallel group, and for speed control two steps of field-shunting are utilised. Two motor-driven blowers, connected in series and fed from one main generator, supply cooling air for the traction motors.

The radiators (oil and water) are cooled by four series motor-driven vertically-mounted propeller fans whose speed is varied by grouping and field weakening under the automatic control of a thermostat which also operates the shutters. Air is drawn through openings in the side of the locomotive and expelled through the roof. During engine-idling periods the main generators are excited to provide power for driving the blowers and radiator fans, but, on movement of the controller to the first power position, this excitation is immediately reduced to zero and then gradually increased to provide a smooth accelerating tractive effort.

Control apparatus of conventional design is employed and is installed in cabinets whose layout was chosen for easy maintenance and accessibility.

Leading dimensions, etc., are quoted on page 341, Appendix.

1000 h.p. Mixed-Traffic Locomotive. Fig. 136 shows a plan and elevation of a 1000 h.p. mixed-traffic locomotive built by Alco-G.E. Intended for the operation of branch lines, this locomotive has had a very wide application ; in fact, certain smaller railroads have changed over completely to diesel haulage and use this type of locomotive for all traffic. Its weight in working order is 106 tons, corresponding to a loading of 26·5 tons on each of the four driving axles. During the war, however, a number of these versatile machines were despatched to the U.S.S.R. and, to limit the axle-loading to 17 tons, two extra carrying axles were incorporated, one on each bogie.

The underframe is of fabricated welded-steel construction with steel floor-plates and has standard buckeye couplers at each end. It is carried on two four-wheel swivel pedestal type trucks which have one piece cast-steel frames spring-supported on side equalisers. Both bogies are arranged to carry two spring nose-suspended traction motors, mounted so that the wheel and axle assemblies can be removed either with or without motor. Standard axle-boxes with end-thrust arrangements are fitted. The motors are geared for a maximum speed of 60 m.p.h.

The superstructure is substantially constructed of steel plates, braced thoroughly and secured to the underframe. Two low hoods, one containing the power equipment and the other the heating boiler and its accessories, are situated one at each end of the driving cab, which is raised above the deck level to provide maximum visibility. The front hood has a large removable section over the engine-generator set, with smaller hatches in it to permit removal of pistons, liners and cylinder heads. At its forward end are situated the radiators and main fan with suitable screens and shutters for air regulation, and at the rear adjacent to the operating cab suitable compartments house the control gear. Adequate ventilation for both hoods is provided by a series of louvres.

On the right-hand side of the cab is the control stand with two control and one brake levers. The two former comprise a combined reverser-motor combination handle and a mechanically-operated throttle, the initial movement of which functions to close the main motor and field contactors. Three motor combinations are used, viz. : all four in series, series-parallel with full field, series-parallel with shunted fields, and the control system is so

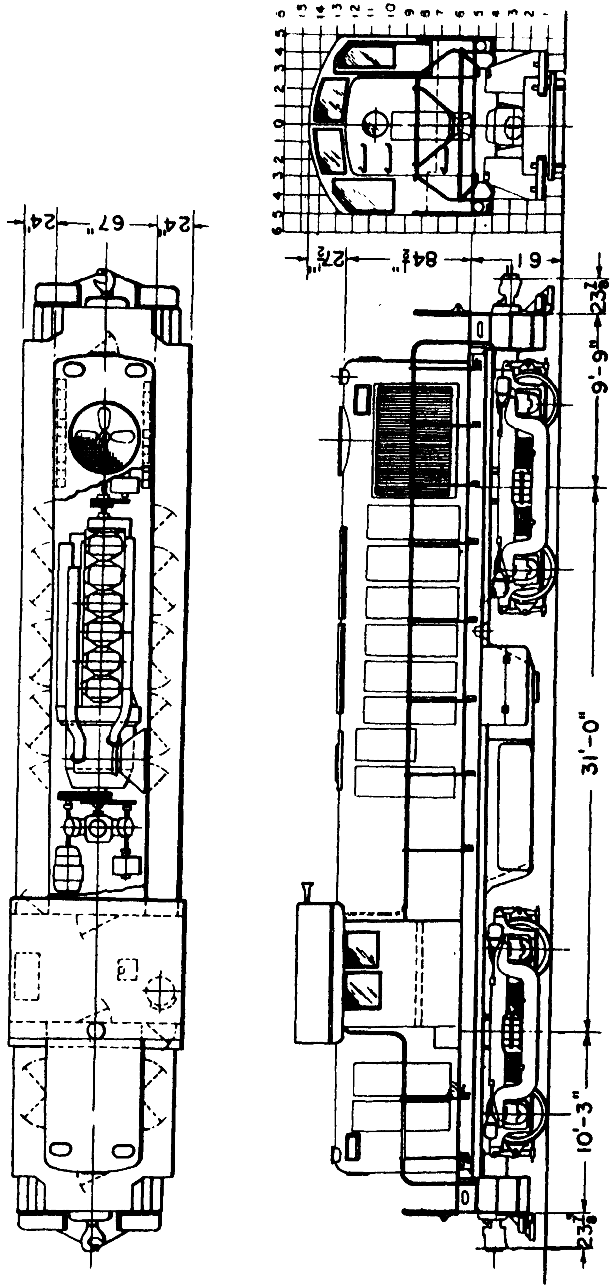


FIG. 136. Alco-G.E. mixed-traffic locomotive (1000 h.p.).

arranged that, when the selector handle is set to one of the two latter combinations, the locomotive starts with the four motors in series effecting transition automatically to the other combinations in turn as and when conditions permit, this being accomplished through the medium of an automatic transfer relay. Automatic and direct air brakes, controlled from the driver's brake valve, are provided on all wheels, together with the necessary connections for train-braking.

Power is derived from an ALCO six-cylinder four-stroke supercharged diesel-engine rated at 1000 h.p. direct-coupled to the main generator, which drives, in addition, an exciter-auxiliary generator set, two traction motor blowers (one over each bogie), compressor and radiator fan through pulleys, belts and gearing. The motor cooling air passes through ducts in the underframe and then through flexible bellows to the traction motors, 1200 cub. ft. per minute being delivered to each machine at maximum engine speed. Load control is achieved by means of the split-pole differential exciter, which maintains an approximately constant generator output throughout the normal speed-range of the locomotive.

A very similar 1000 h.p. shunting locomotive is also constructed by Alco-G.E., but with different gearing and no boiler compartment. These changes result in some modification of the main dimensions—see Appendix, page 338.

Shunting Locomotives. The three manufacturers named so far all produce two standard shunting locomotives, a 600/660 h.p. model and a 1000 h.p. model. These machines are generally similar in characteristics, being double-bogie locomotives with one engine-generator set, four traction motors and single-station control from a cab situated at one end of the superstructure, the remainder of which comprises a large hood enclosing the main power equipment. The Appendix gives comparative details and Fig. 137 shows an Electromotive 660 h.p. locomotive, and an Alco-G.E. of the same power.

Fairbanks-Morse 1000 and 6000 h.p. Locomotives. Newcomers to the diesel-electric locomotive field, Fairbanks Morse and Company, have produced two interesting locomotives.

The first of these is a 107 ton double-bogie shunting locomotive powered by a six-cylinder two-stroke opposed-piston engine rated at 1000 h.p. One-piece cast-steel bogies are employed, each with

two traction motors, these being cooled by two blowers, the foremost motor-driven and the rear one belt-driven on a common shaft with a small generator which supplies the radiator fan motor. The underframe is a one-piece fabricated steel unit with standard

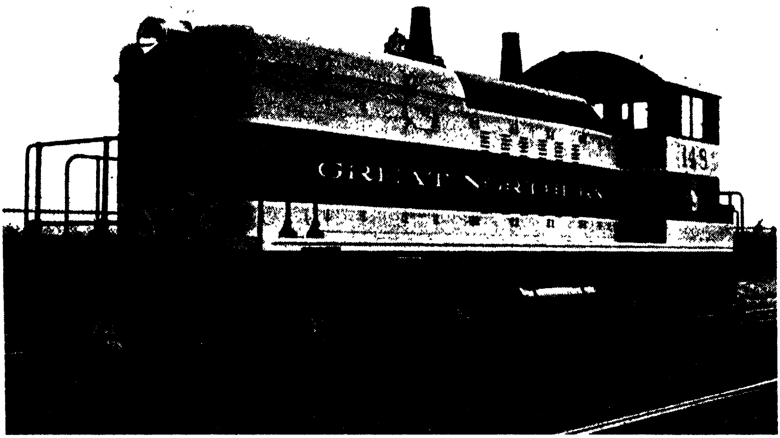


FIG. 137 (i). Electromotive 660 h.p. shunting locomotive.

buffer beams and buck-eye couplers, and has vestibule-type steps at each corner to permit adequate access to and across the locomotive when engaged in shunting duties.

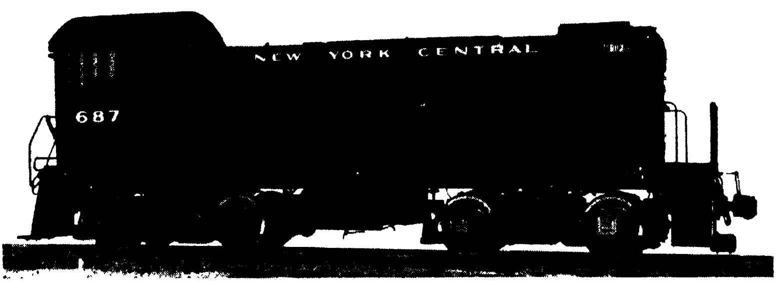


FIG. 137 (ii). Alco-G.E. 660 h.p. shunting locomotive.

Due to the greater height of the O.P. engine, the power-equipment compartment could not be reduced in height as with other shunters, but, as will be seen from the illustration, ample visibility

is provided for. The electrical equipment is mounted at the rear of this compartment, and is accessible from the driving cab through hinged doors. An excellent illustration of this appears in Fig. 138B.

The 6000 h.p. mixed-traffic locomotive, forerunner of its class, built in 1946 is generally similar to the other U.S. passenger locomotives, being made up of three units (two " A " and one " B ") each of 2000 h.p. In contrast to these other makes, however,

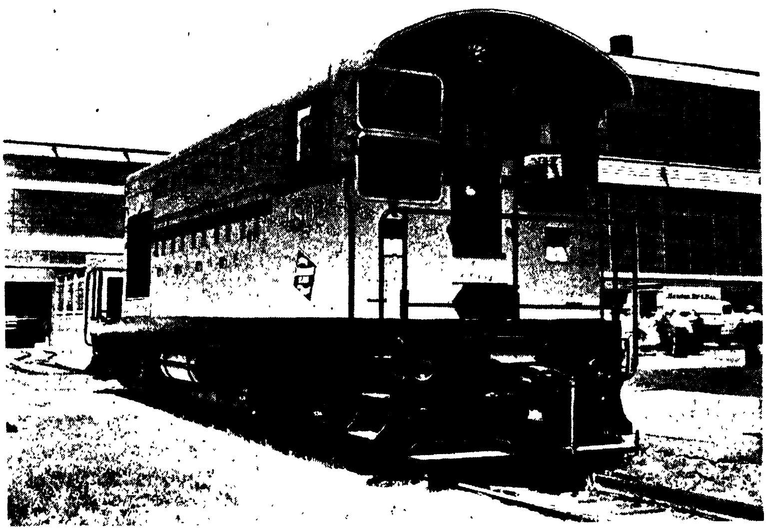


FIG. 138A. 1000 h.p. shunting locomotive powered by 6-cyl. O.P. engine.

each unit is powered by one ten-cylinder two-stroke opposed-piston engine which delivers 2100 h.p. to the main generators and auxiliaries. The usual six-wheel bogies with only the outer axles driven, i.e. with two traction motors per bogie, are employed. Fig. 139 shows plan and elevation of an " A " or driving unit. The latest locomotive from Fairbanks-Morse is a four-unit 8000 h.p. machine made up of two " A " and two " B " units.

Baldwin 2000 h.p. Shunting and Freight Locomotive. To fulfil the requirements of the Chicago belt railways which require a powerful locomotive for short-distance freight and shunting work, Baldwin-Westinghouse have recently completed a 2000 h.p.

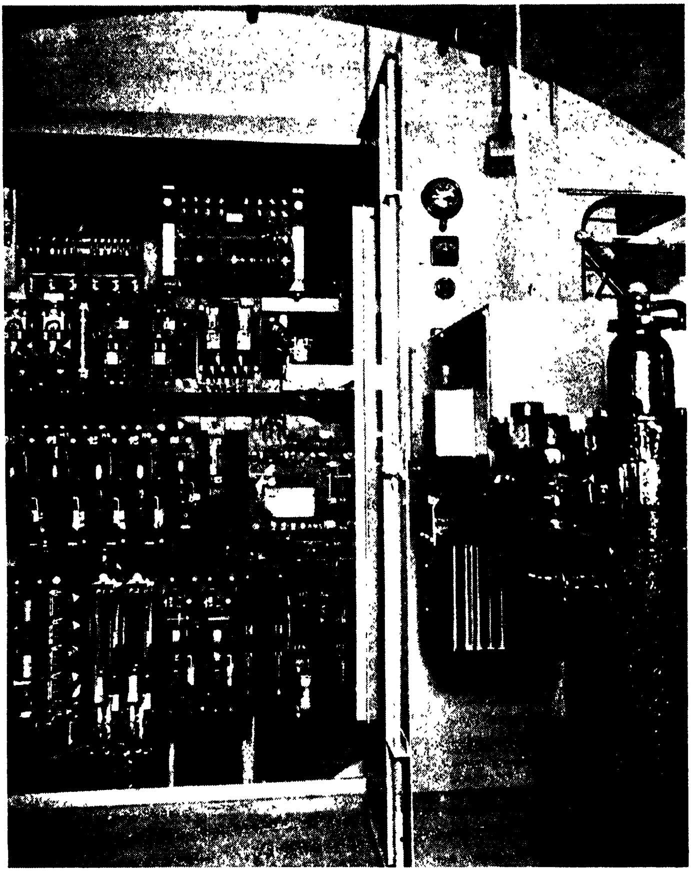


FIG. 138B. Cab-interior of 1000 h.p. shunting locomotive showing accessibility of electrical equipment.

central-cab locomotive which is illustrated in Fig. 140. Power is supplied by two six-cylinder 1000 h.p. engines transmitted through six traction motors, i.e. one per axle. The locomotive is a good example of combined power and flexibility of operation.

The Twin-Engined Central-Cab Locomotives. A very large range of locomotives is manufactured by the Whitcomb Locomotive and Porter organisations. In general, these have a maximum output range from, approximately, 600 h.p. down to 200 h.p. and are arranged for various speeds, gauges and axle-loadings so that they can be used for short-distance freight, shunting or

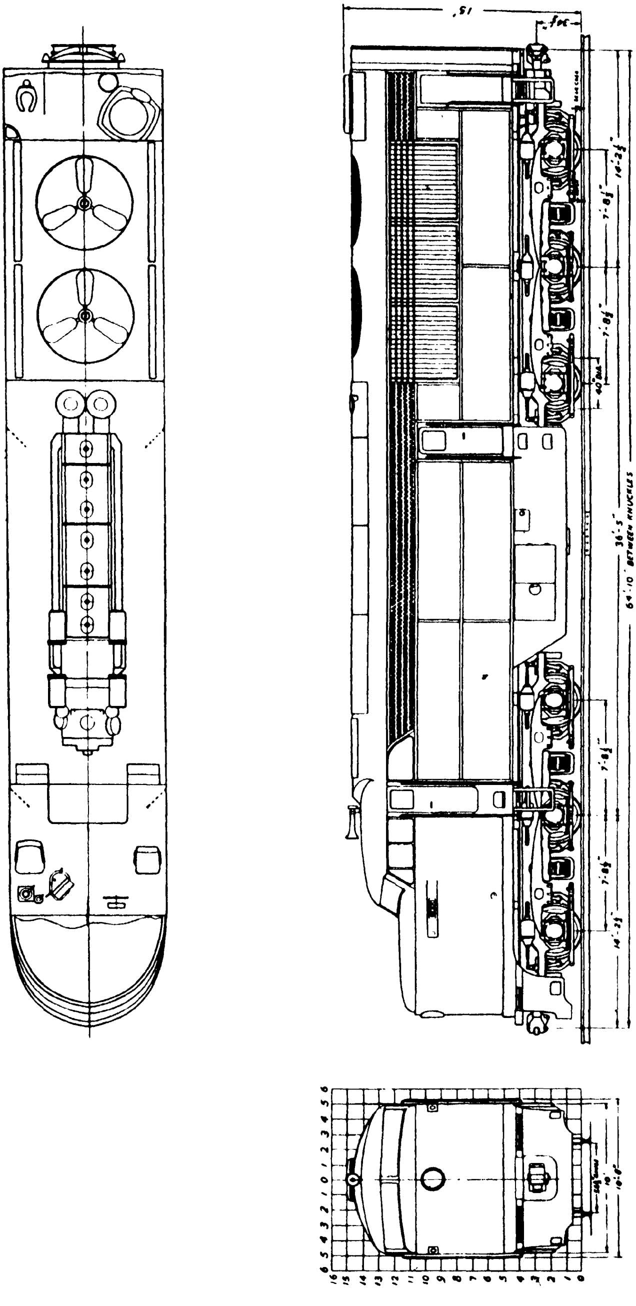


FIG. 139. General arrangement of leading unit—2000 h.p. locomotive powered by ten cylinder O.P. engine.

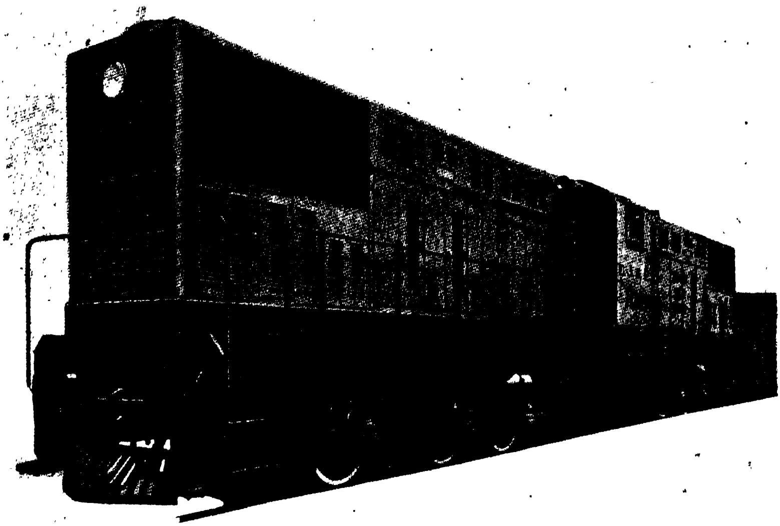


FIG. 140. Baldwin-Westinghouse 2000 h.p. shunting locomotive—Elgin Joliet and Eastern Railroad, U.S.A.

works duties. Fig. 141 shows a Porter 76 ton 500 h.p. unit and a Whitcomb 72 ton 650 h.p. machine.

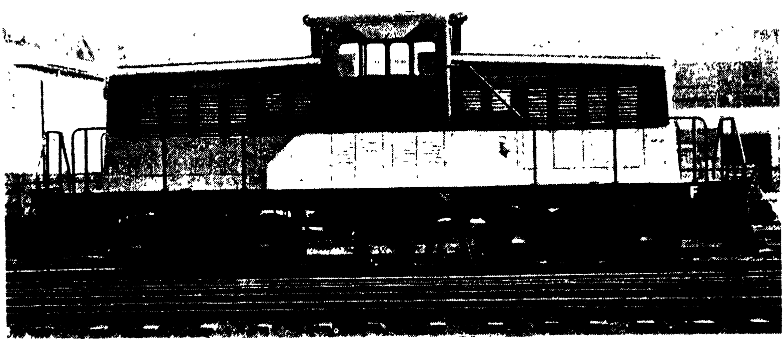


FIG. 141A. Porter 76 ton 500 h.p. locomotive.

The latter is powered by two Buda six-cylinder four-stroke mechanically-driven supercharged engines mounted one under each hood, the compact arrangement produced being clearly visible

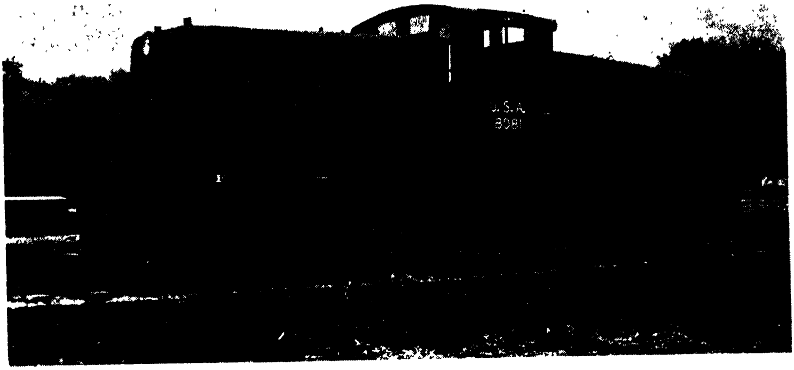
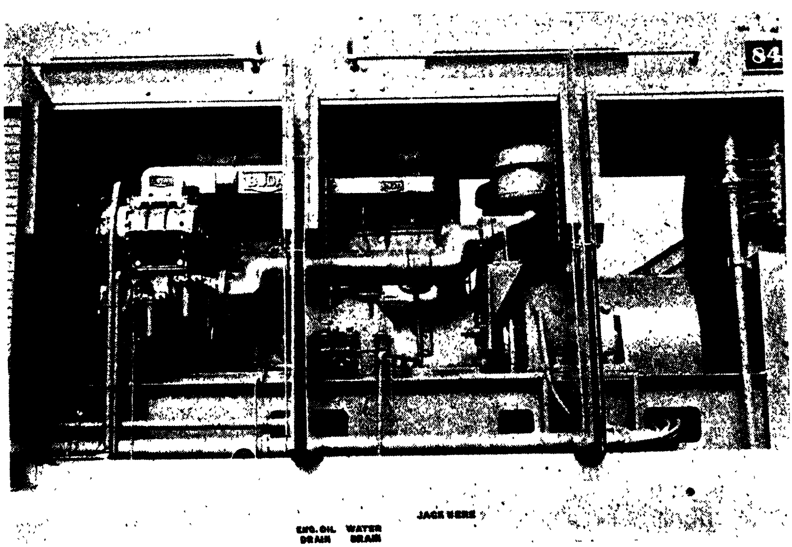


FIG. 141B. Whitcomb 72 ton 650 h.p. locomotive.

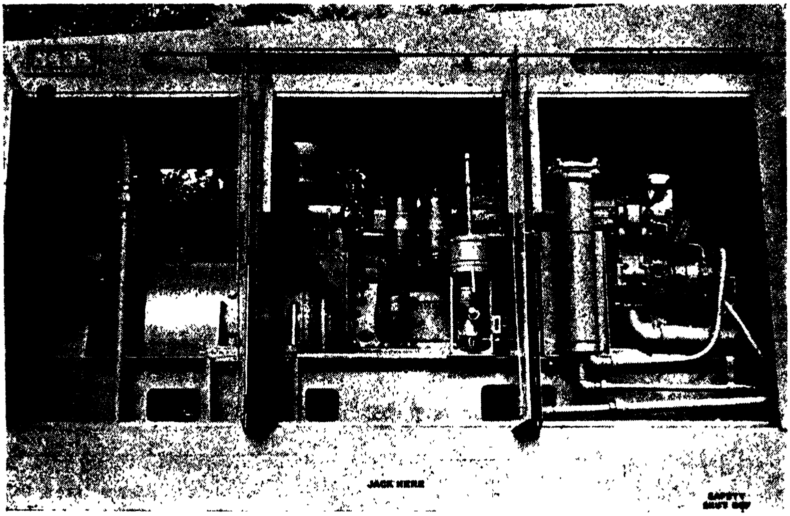
in Fig. 142 with the various drives for compressor, supercharger, auxiliary generator, etc. A fabricated underframe comprises rolled steel shapes and braces reinforced where necessary and is



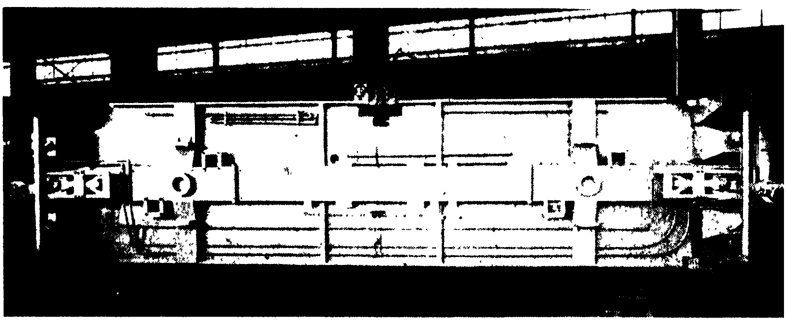
(i) R.H. side of Buda engine.

FIG. 142. Whitcomb 72 ton 650 h.p. shunting locomotive.

supported by two four-wheel side equalised swivel trucks, built up of welded sections. Each bogie has two single-reduction geared nose-suspended motors geared for a maximum speed of



(ii) L.H. side of Buda engine.

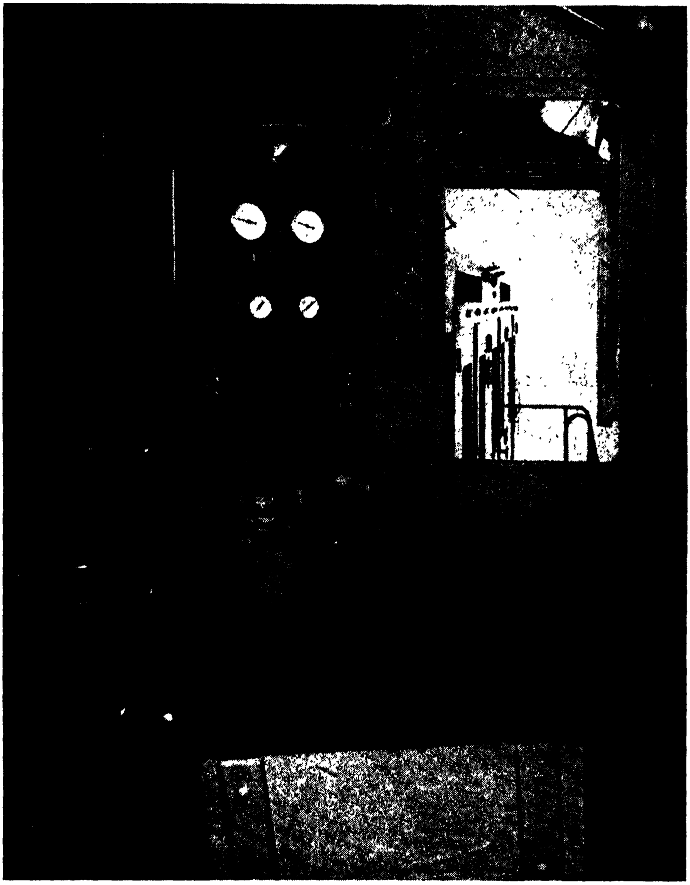


(iii) Main underframe.

FIG. 142. Whitcomb 72 ton 650 h.p. shunting locomotive.

40 m.p.h., and capable of a total maximum tractive effort of 40,000 lbs. Two motors are permanently connected in parallel with each generator, and automatic transition is provided to the shunted-field connection. Load control is by the twin self/battery field

arrangement in combination with a mechanically-operated throttle from the control stand.



(iv) Driving position.

FIG. 142. Whitcomb 72 ton 650 h.p. shunting locomotive.

The narrow gauge locomotives are frequently of the type shown in Fig. 143, a 45 ton 300 h.p. machine with only two traction motors, these driving the inner axles of each bogie through triple reduction gears and the outer axles by means of side-rods. Maximum speed is, of course, lower, being 20 m.p.h. in this case.

Details of certain of these locomotives only are included in the

Appendix, the complete range being too extensive to permit inclusion in full, especially as variation from type to type is small.

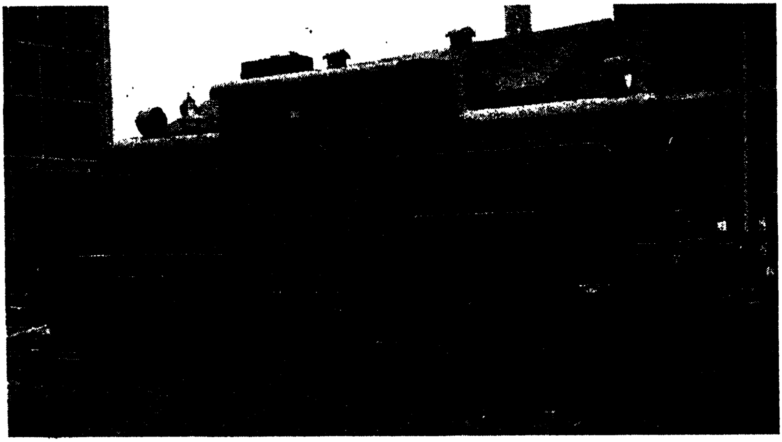


FIG. 143. 45 ton 300 h.p. narrow-gauge locomotive.

The 40-ton Twin-Engine General-Purpose Locomotive. One of the most popular light shunting and local freight traffic diesel-locomotives in the U.S.A. is the 40 ton unit powered by two Caterpillar eight-cylinder V engines of 190 h.p. each. Similar models are built by Whitcomb, Alco.-G.E., Porter, Davenport Locomotive and others.

In general, the higher engine speed (550–1000 r.p.m.) and lower power involved permits the employment of lightweight electrical machines. The General Electric Company in particular utilise a small traction motor operating up to 4000 r.p.m., and double reduction-geared to give a maximum speed of 35 m.p.h. Fig. 144 shows the Davenport Locomotive Works model complete, and with hoods and cab removed. Further details are given in the Appendix, page 341.

The Two French 4000 h.p. Main-Line Locomotives. In 1938 two experimental express passenger diesel-electric locomotives were introduced by the French National Railways and, after more than five years in storage during the occupation of France, these machines finally came into regular service between Paris and Dijon early in 1945. Full details are given in the Appendix, page 326, and it will be seen therefrom that the two

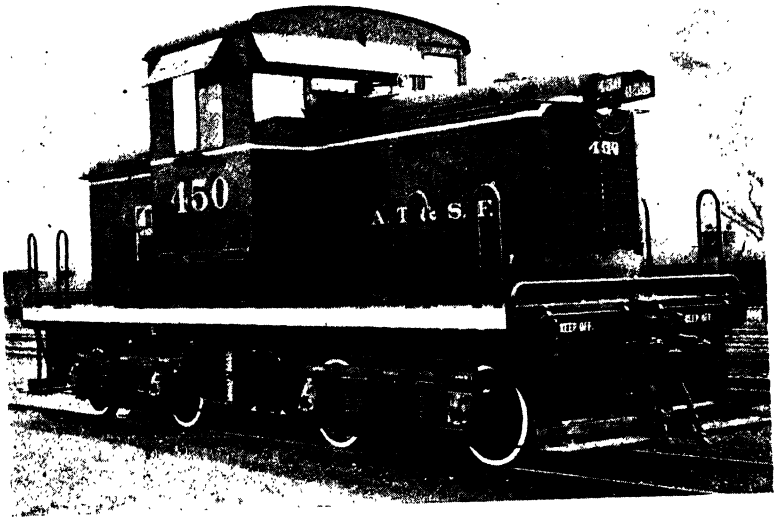


FIG. 144 (i). Davenport-Caterpillar 40 ton 380 h.p. locomotive.

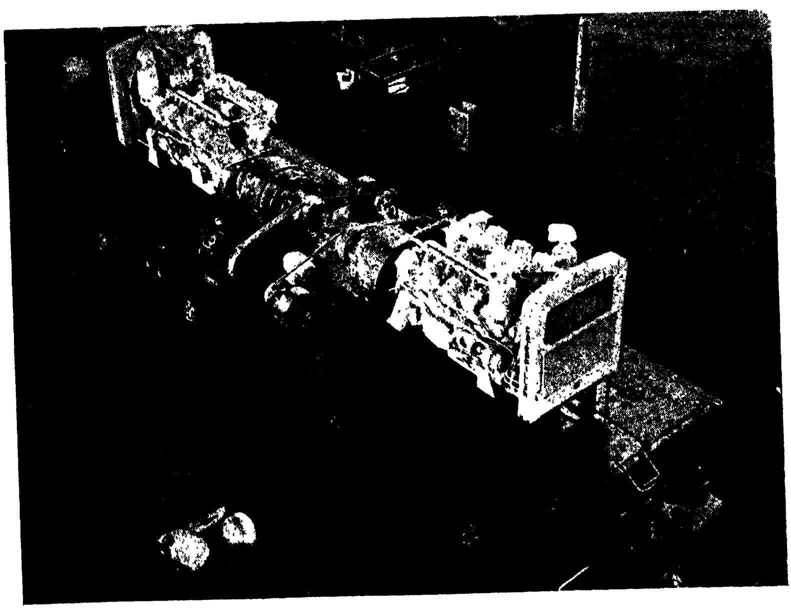


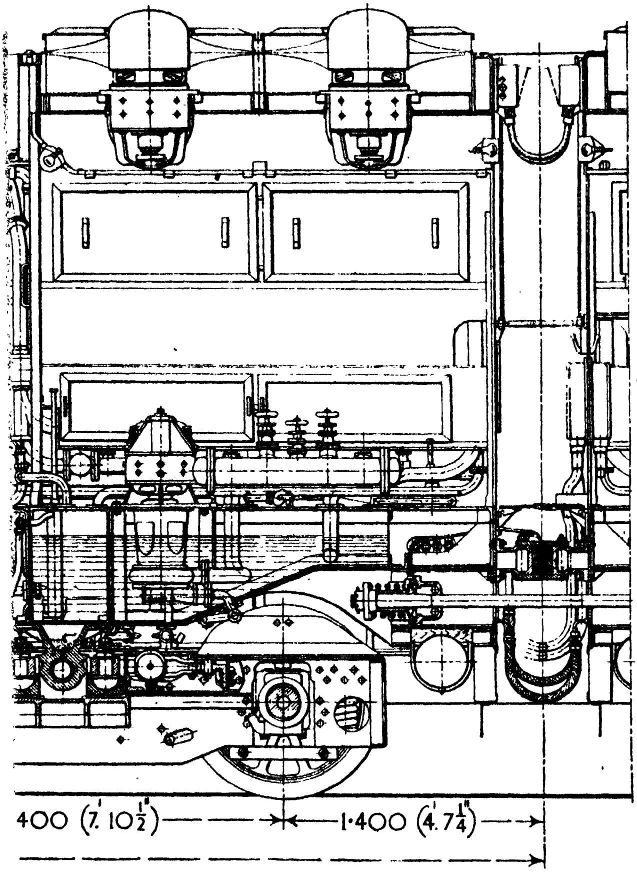
FIG. 144 (ii). Davenport-Caterpillar 40 ton 380 h.p. locomotive.

locomotives were individual designs set out to cover the required specifications and, as such, bear considerable resemblance to each other.

The first of these locomotives is shown in Fig. 145, together with a folding elevation of half the unit. Built by the Cie de Forges et Aciéries de la Marine et d'Homecourt with electrical equipment by the French Jeumont organisation the locomotive comprises two identical halves each powered by one Sulzer 12-cylinder double-bank 2200 h.p. engine. One inch welded steel plates braced by

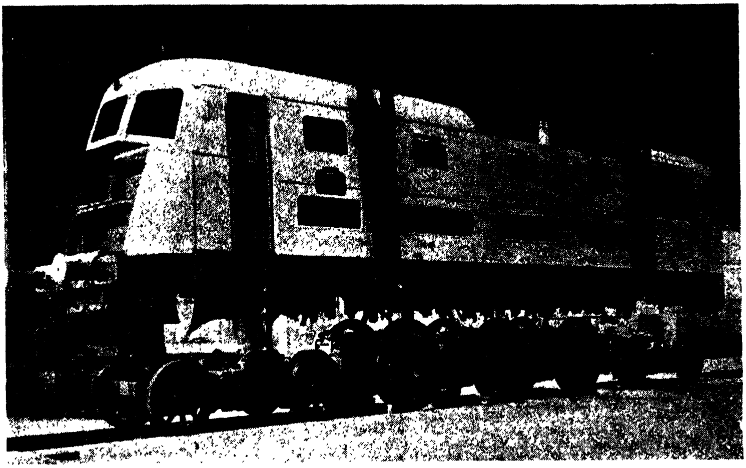
FIG. 145. 4400 h.p. diesel-electric passenger locomotive—French National Railways.

end-beams and bogie pivot supports make up the underframe, additional stiffening being provided by the engine mountings and the crossbars situated above and between the axles for traction motor support. The motors are rigidly attached to the underframe and are each situated adjacent to their appropriate axles, twin gears and quill and cup drives being employed to transmit the tractive power to the driving wheels. Three driving axles per half-locomotive are rigidly held in the frame, the outer ends of which are supported by two bogies carried on spherical pivots and recentred by a combination of laminated and coil springs, this layout producing an axle classification $2\text{–}C_0\text{–}2+2\text{–}C_0\text{–}2$, the two units being connected by drawgear with small buffers.

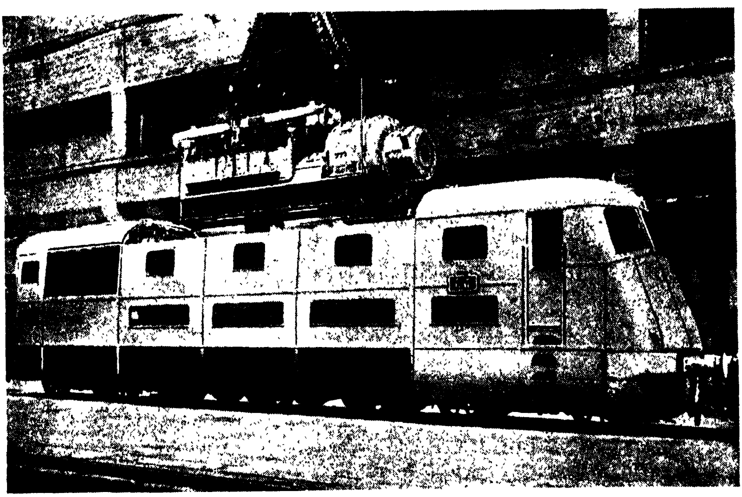


400 (7' 10½")
1·400 (4' 7¼")

Fig. 146 shows this locomotive in course of erection with the cab, running gear and power unit ; note the hatchway in the roof



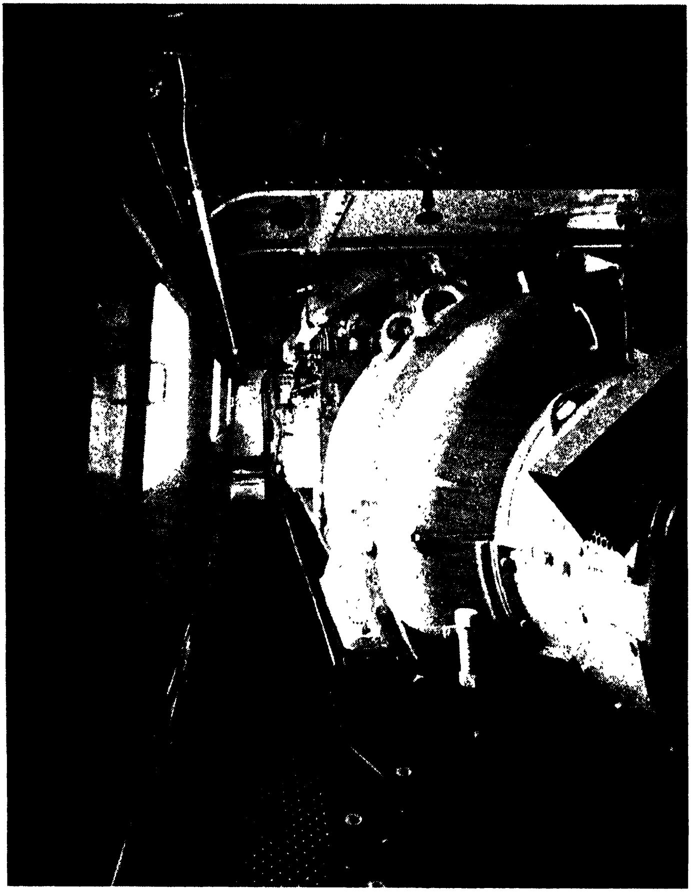
(i) The fitting of the frame and superstructure.



(ii) Installation of the Sulzer power unit.

FIG. 146. Two stages in the erection of the S.N.C.F. passenger locomotive.

through which the engine is installed. Fig. 147 shows the interior of the engine room and ample clearance for walking past the main engine, remarkable for such a power unit. Also shown is an interior view of the driving cab.



(i) Engine room.

FIG. 147. Interior of 4400 h.p. locomotive.

The power equipment of each unit comprises the aforementioned engine, a ten-pole main generator, an auxiliary generator, an axle-driven exciter and three traction motors with the necessary control-gear, batteries, compressor, etc. Load control is carried out by the axle-driven exciter operating in conjunction

with a servo-field regulator which controls the battery field current fed to this exciter. Forced ventilated traction motors are employed, permanently connected in parallel and arranged for automatically controlled field-shunting on the higher speeds. In the event of one engine failing, the two sets of motors can be connected in series with the generator of the other unit, an action which enables the locomotive to continue at reduced speed.

(ii) Driving compartment.
FIG. 147. Interior of 4400 h.p. locomotive.

The other locomotive is very similar, as will be seen from the photograph (Fig. 148) and drawing. As in the first machine, each half comprises a central compartment containing the engine-generator set flanked at its inner end by the radiators, fans and auxiliary machinery, which in this case includes a separate auxiliary-generator set driven by a 150 h.p. Saurer engine. The outer end is occupied by the electrical equipment and driving compartments, the whole being enclosed by an outer casing which is designed to provide a pleasing and effective streamlining extending to below axle-level. A ball socket and rod articulation coupling is employed to connect the two halves together, and a flexible corridor gangway enables the locomotive crew to pass between units during operation.

In this locomotive, power is provided by two 2100 h.p. twin-engines, each half of which comprises a six-cylinder four-stroke supercharged engine rated at 1050 h.p. with its own generator and exciter (Fig. 115), which may be started and operated independently of the other bank on the same base. Six twin-armature traction motors drive the axles through single gears with Meyforth-Sécheron quill and spring-cup flexible drives. The electrical connections of each half-locomotive unit are such that one armature from each of the three twin motors is connected across No. 1 main generator terminals, and the other armatures in parallel with

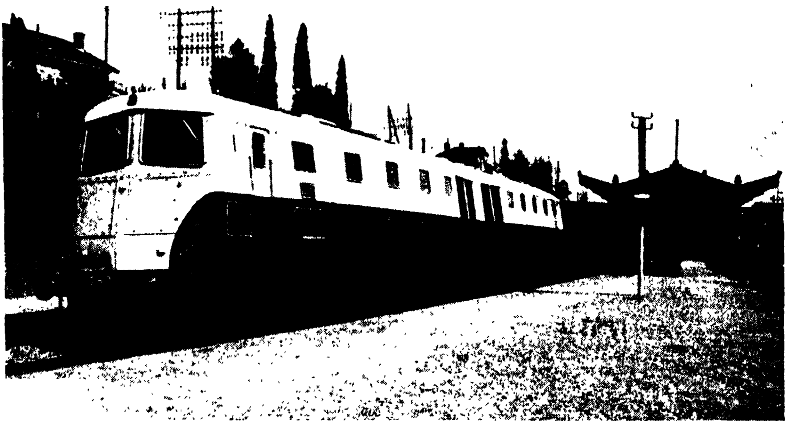


FIG. 148. 4200 h.p. express passenger locomotive—French National Railways.

No. 2 machine. Load control is achieved by the bridge circuit method using Simplex-Sécheron regulators, one for each engine.

4400 h.p. Mixed-Traffic Locomotive for Rumania. The remaining member of the European 4000 h.p. trio is the Rumanian mixed-traffic locomotive, designed for operation of 600 ton trains over the Campina–Brassov section on the international main line where gradients range between 1 in 40 and 1 in 50 with 900 feet radius uncompensated curvature. As built, the locomotive weighs 218 tons, of which 148 tons are available for adhesion (i.e. 16 tons per axle). This enables a maximum tractive effort of 81,500 lbs. to be developed, sufficient for starting the heaviest trains on the above gradients.

The axle-classification is $2\text{–}D_0\text{–}1 + 1\text{–}D_0\text{–}2$, the locomotive being constructed in two identical halves coupled together and

operated in multiple unit. Each half is powered by a Sulzer twelve-cylinder double-bank 2200 h.p. engine with a combined main and auxiliary generator in which the smaller machine is almost completely within the outer end of the larger. Eight standard series traction motors, one per axle, are rigidly attached to the underframe, the drive being transmitted from each by means of a flexible quill and cup mechanism. The motors are connected in two parallel groups, one of which is supplied by each engine-generator set operating in conjunction with a servo-field regulator for control of the engine-loading.

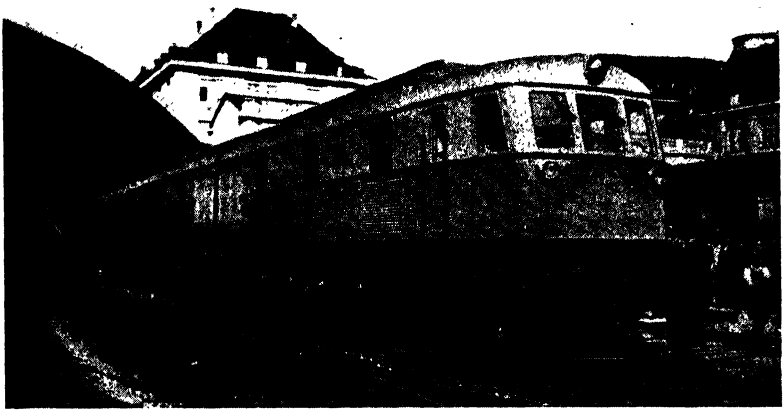


FIG. 149 (i). Rumanian 4400 h.p. mixed-traffic locomotive.

Each 14-wheeled unit is carried on a welded steel underframe in which are incorporated supports for the engine-generator set, motors, etc. The superstructure is divided into a driving cab, a generator compartment, an engine room and a radiator compartment, with a general internal layout arranged to provide two side corridors from the driving cab down each side of the power unit, combining into a central passageway between the radiators which leads to the flexible gangway between units. All statistics are given on page 335.

1200 h.p. Locomotive for Branch-Line Service. Fig. 150B shows the plan and elevation of a Swiss 1200 h.p. locomotive, two of which were constructed in 1939 for the operation of branch lines where electrification is not an economical proposition. The total weight of 64 tons, which corresponds to an axle-loading of

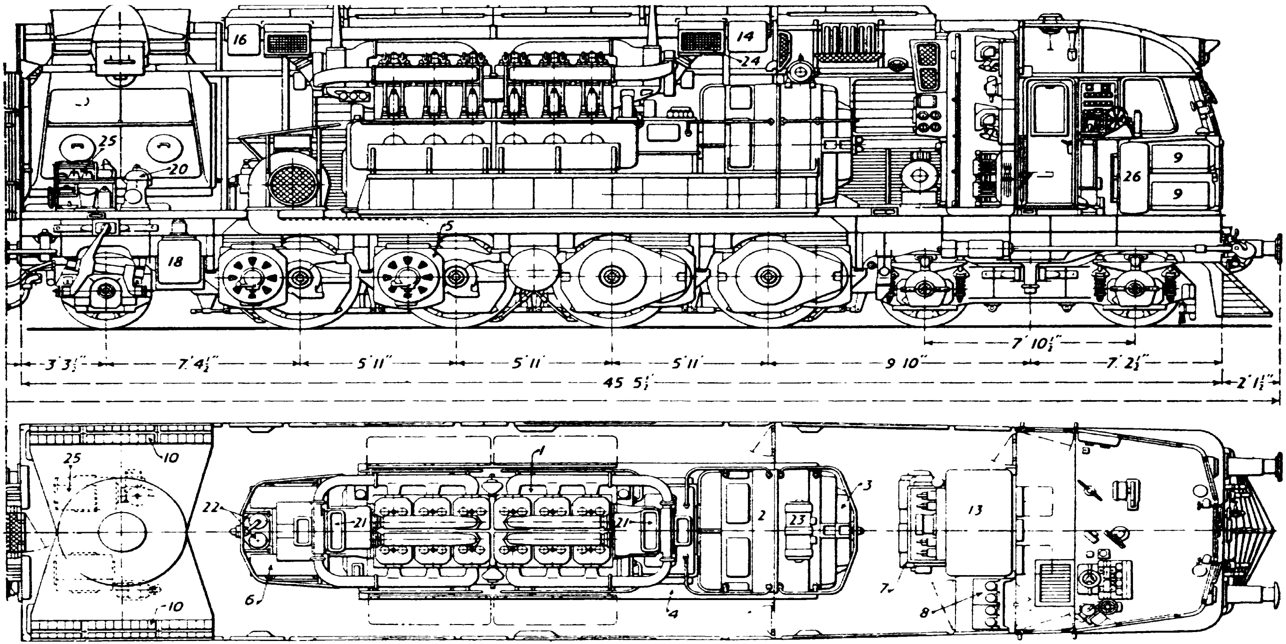


FIG. 149 (ii). Rumanian 4400 h.p. mixed-traffic locomotive.

1. Main engine.
2. Main generator.
3. Auxiliary generator.
4. Engine-generator underframe.
5. Traction motors.
6. Traction motor blower set.
7. Motor-compressor set.
8. Main control equipment.
9. Battery.
10. Water and oil coolers.
11. Radiator fan.
12. Radiator fan motor.
13. Main fuel tank.
14. Fuel service tank.
15. Main water tank.
16. Auxiliary water tank.
17. Cooling water pump.
18. Lubricating oil tank.
19. Lubricating oil auxiliary pump.
20. Lubricating oil cleaner.
21. Büchi supercharger.
22. Lubricating oil filter.
23. Motor-generator set.
24. Air filter.
25. Tool chest.
26. Control air reservoir.

16 tons, makes the locomotive suitable for use on track of light-weight construction, especially as the traction motors, though mounted on the bogies, are sprung and employ the Brown-Boveri flexible-disc drive for torque transmission. A simple layout has been adopted with a driving cab at each end and in general appearance the locomotive is very similar to the latest electric units, though rather smaller in size.

Power is provided by a Sulzer eight-cylinder supercharged engine rated at 1200 h.p. with a speed of 750 r.p.m. This drives

FIG. 150A. Swiss 1200 h.p. 64 ton mixed-traffic locomotive.

a main generator, heating generator and auxiliary generator, the separate heating supply being necessitated as most Swiss rolling stock is now fitted for electrical heating from an 800–1000 volt $16\frac{2}{3}$ cycle A.C. supply. The circuit connections of the locomotive are as shown in Fig. 124, the four traction motors being connected in parallel with the generator and arranged for forced ventilation. Load control is by the Sulzer-Brown Boveri servo-field regulator system. (See page 336 (Appendix) for full particulars.)

Danish Branch-Line Locomotive. The railways of Denmark possess a large number of light branch lines traversing the level fertile regions, and during recent years a considerable number of light mixed-traffic diesel-electric locomotives have been introduced

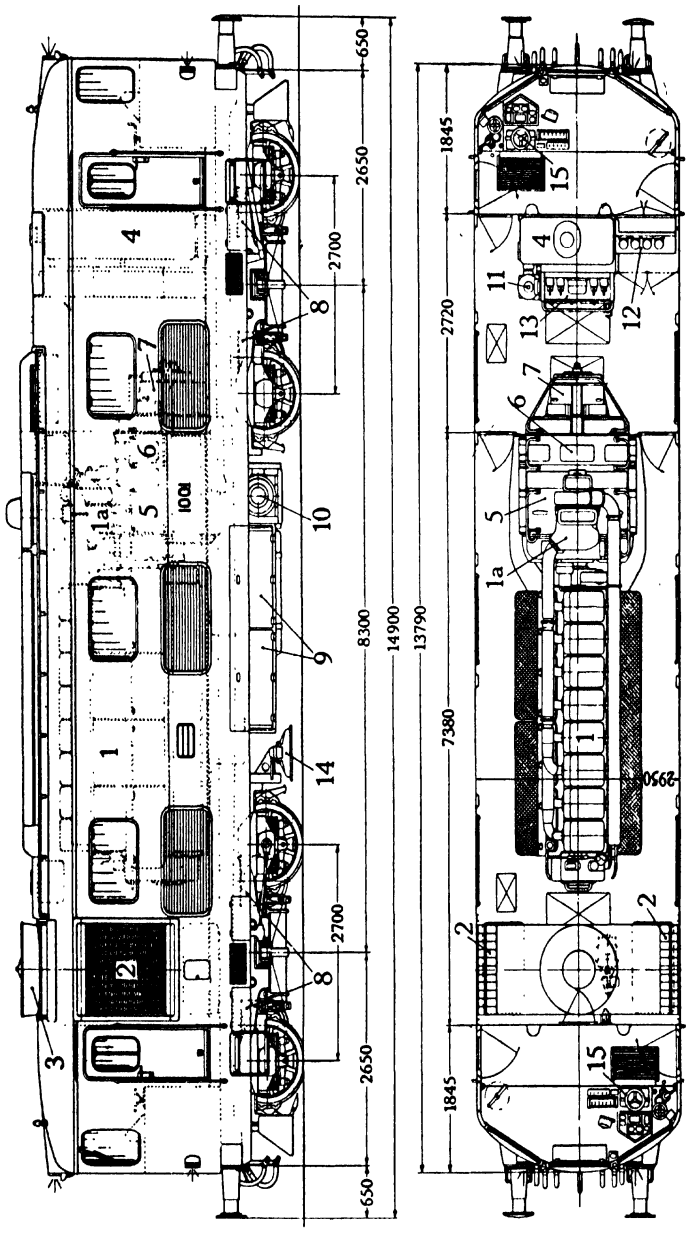


FIG. 150B. Swiss 1200 h.p. 64 ton mixed-traffic locomotive.

1. Diesel engine.
1a. Supercharger.
2. Water and oil cooler.
3. Radiator fan.
4. Main fuel tank.
5. Main generator.
6. Single-phase A.C. heating generator.
7. Exciter.
8. Traction motor with flexible disc drive.
9. Battery.
10. Motor-compressor set.
11. Vertically mounted motor-generator set.
12. Main control cubicle.
13. Auxiliary control cubicle.
14. Main fuse panel.
15. Main controller.

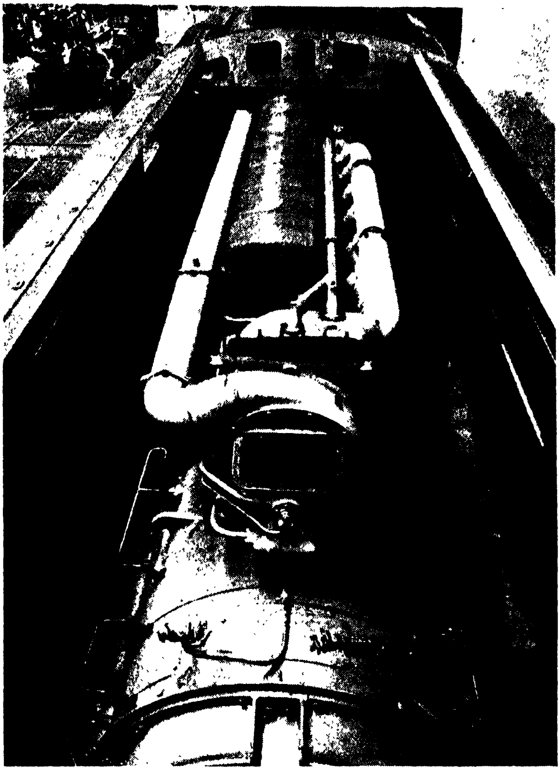


FIG. 151A. Engine-room of Swiss diesel-electric locomotive.

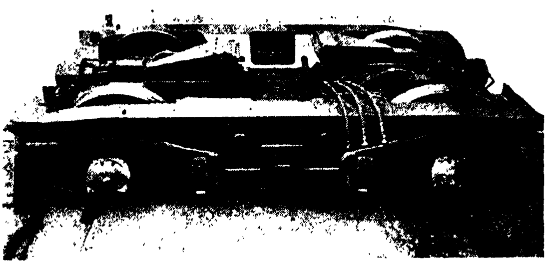


FIG. 151B. Diesel-electric locomotive driving bogie.

on these routes. The popular size is about 400 to 450 h.p. and Fig. 152 shows a typical 450 h.p. locomotive of this type. Built by A. S. Frichs, the machine is simple in arrangement, the superstructure comprising a central engine-generator and radiator compartment with a driving position at each end, the outer appearance being of the box-cab type, as a maximum speed of only 50 m.p.h. is required.

Motive power is provided by a six-cylinder engine of the type shown in Fig. 118C. This engine is direct-coupled to a generator with overhung auxiliary generator and is arranged to supply the

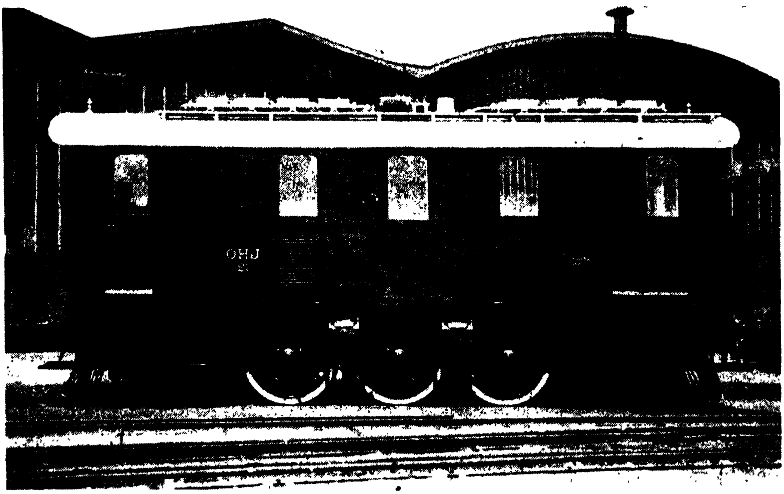


FIG. 152. 450 h.p. branch-line locomotive (Denmark).

traction motors which are connected permanently in parallel. A rigid driving wheelbase is adopted with three axles, each powered by one traction motor, and is guided by a two-wheel pony truck at each end. As the total weight in working order is 48 tons, this wheel arrangement (1–C_0–1) enables the very low axle-loading of less than 12 tons to be achieved, so making the locomotives capable of operating over the most severely weight-restricted routes.

Shunting Locomotive in France and Britain. The various French railways carried out a number of experiments involving diesel-electric shunting locomotives in the early part of the last decade, as a result of which the following locomotive was evolved after the grouping into one national concern. Three only were

constructed before the war, and in certain ways standard U.S. practice has been adopted in that the locomotive is carried on two

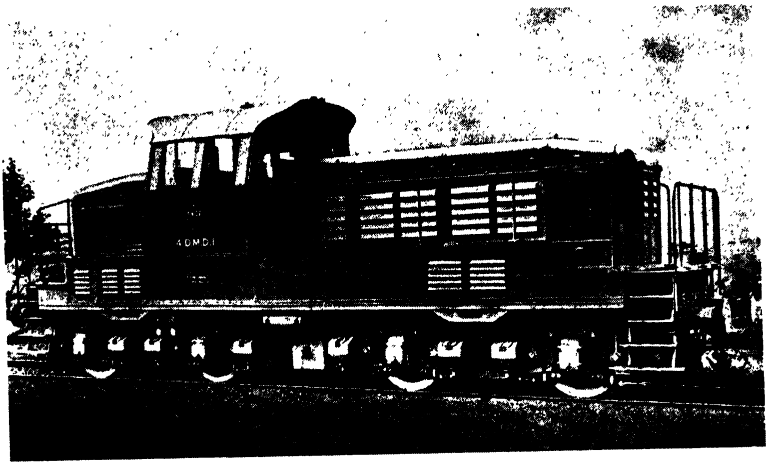


FIG. 153A (i). French National Railways 635 h.p. shunting locomotive.

four-wheel bogies and has a raised driving cab flanked by two hoods containing the equipment. The larger hood holds the

FIG. 153A (ii). French National Railways 635 h.p. shunting locomotive.

main engine-generator set with radiator and the smaller, certain auxiliaries and control equipment.

Three views of the locomotive are shown in Fig. 153. Rated at 635 h.p., it is designed for a maximum speed of 31 m.p.h. and is capable of hauling 1000 tons on level track at a speed of 18·6 m.p.h. for 30 minutes. The weight in working order is 68 tons, resulting in an axle-loading of 17 tons. Power is provided by a

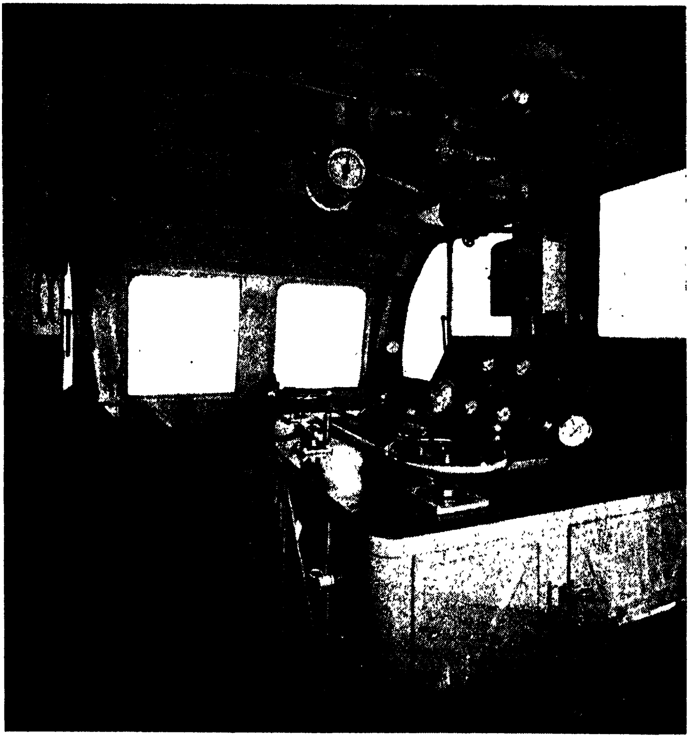


FIG. 153B. Driving cab of French shunting locomotive.

six-cylinder Sulzer engine with Rateau blower, which is mounted together with the main generator and overhung exciter on a rigid bedplate, an arrangement making the removal for maintenance purposes a simple matter.

In Great Britain, approximately, one hundred diesel-electric shunting locomotives are in service, the majority of which are of the well-known English Electric 350 h.p. six-coupled model, a number of which are in service on each of the four main-line railways.

Two experimental models, one Armstrong-Whitworth and one English Electric, were introduced in 1934 and followed by further similar machines in 1936. These two are illustrated in Fig. 154.

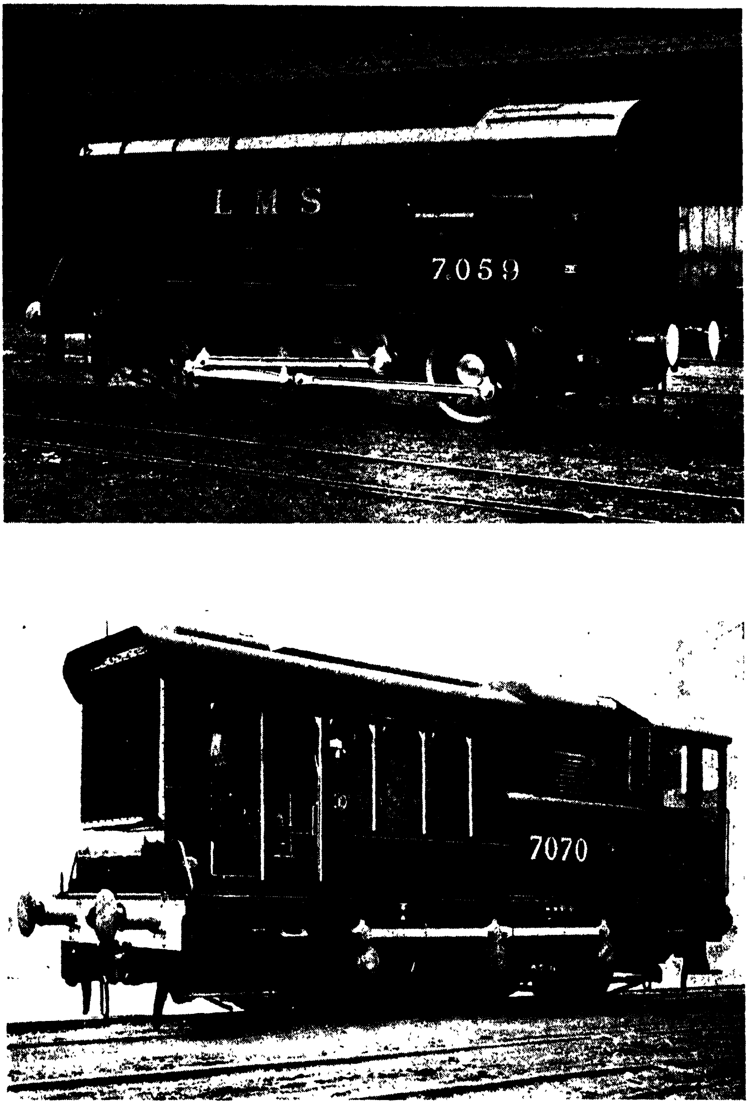


FIG. 154. Armstrong-Whitworth and English Electric shunting locomotives.

First, comes the Armstrong 400 h.p. machine with an Armstrong-Sulzer six-cylinder engine and a single double-reduction geared motor driving the three coupled axles by a jackshaft and connecting rods. Secondly, the English Electric model, which, at this stage in its evolution, had two nose-suspended self-ventilated traction motors, was geared for a maximum speed of 40 to 50 m.p.h. so that it could be used for light mixed-traffic duties if required. This model was supplied to the Sudan and to South Africa in addition to three major British lines, and in the South African model it is worthy of note that, to enable the full engine power to be developed at an altitude of 6000 feet, a seven-cylinder engine, normally rated at 410 h.p. was fitted.

The next stage in the evolution was the construction of forty double-reduction geared locomotives designed for hump-shunting at 2 m.p.h., and for a maximum speed of 20 m.p.h. Tractive effort is developed by a single forced-ventilated motor, mounted in the frame between the main generator and the driving compartment, the drive being transmitted by a jackshaft with coupling and connecting rods.

During the war a further modification was introduced in a return to the two nose-suspended traction motors, but now force-ventilated and driving through double-reduction gearing. Fig. 155 shows a locomotive of this type, numbers of which have been supplied to the Ministry of Supply, to the London, Midland and Scottish, London and North Eastern, and Great Western Railways, (now British Railways) and to Egypt and the Malay States.

In construction these locomotives are set out in the simplest possible manner to enable maintenance to be carried out quickly and easily. The main underframe is carried on three coupled axles, the standard arrangement for a considerable proportion of steam shunting locomotives, and is arranged with the leading and trailing axles driven by two 135 h.p. traction motors. Power is provided by a six-cylinder 350 h.p. engine with direct-coupled generator and belt-drawn exciter-blower and compressor sets, the whole unit being carried on three bearers to allow for flexing of the main frames. At the front end of the engine and the locomotive is situated the main radiator with a large belt-driven air-circulating fan. The driving compartment is situated at the rear end and has a desk cubicle type controller which contains almost all the control equipment. Battery boxes are attached to the

upper surface of the running plate at each side of the locomotive adjacent to the driving cab, and the main fuel tank is similarly positioned centrally on the main frames. A small point, worthy of mention, however, is the provision of a small electric cooker to enable the crew to have warm meals.

Recently, another rival to this type of locomotive has appeared on trial. Generally similar to the latest English Electric model it has been produced by the Brush Electrical Engineering Co. and has some novel ideas as regards Great Britain.

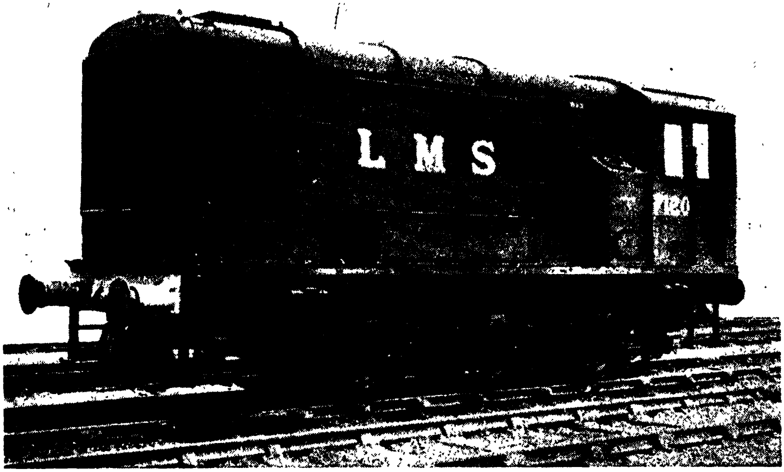


FIG. 155. Latest type of British diesel-electric shunting locomotive.

Power is obtained from a four-cylinder, two-stroke Petter engine rated at 400 b.h.p., and as a result of the reduction in engine size, ample space is available between engine and radiator to accommodate the auxiliaries. These include a small two-cylinder engine driving a compressor which is used for compressed-air starting of the engine, a feature which considerably reduces the size of battery to be carried on the locomotive. Provision is made for " tow-starting " and should a customer desire normal electric starting, this is provided for in the generator windings and only a larger battery would be required.

Brush are also manufacturing much of the electrical equipment for five shunting locomotives under construction by Coras

Iompair Eireann (Irish Railways). These locos follow the general trend of British shunters but have a 535 h.p. supercharged Mirrlees engine.

The Appendix contains particulars of the various types of locomotive covered by this general section—see pages 327–330, 354, 355.

Messrs. Crompton-Parkinson, who before the war worked in conjunction with Sir W. G. Armstrong-Whitworth on a number of diesel-electric locomotives, have recently produced a prototype diesel-electric shunting locomotive suitable for railway or works shunting.

Power is supplied by an eight-cylinder V-type Paxman-Ricardo series RPL engine which with cylinders of $9\frac{1}{2}''$ bore by $12''$ stroke is de-rated down to 400 h.p. at 750 r.p.m. A flexible coupling is used between engine and generator and the combined unit is arranged for three-point suspension from the chassis. The engine-generator set is fitted with the Crompton-Armstrong version of the servo-field regulator. The control gear has been newly developed and incorporates a change-over switch for converting the locomotive from slow-speed hump-shunting to a light branch-line type capable of 40 m.p.h.

A stout plate-frame construction is used with three axles carried in roller bearings. Each axle is driven by a nose-suspended single-reduction-geared traction motor, force-ventilated with filtered air by an engine-driven blower. Engine, generator, motors, axles, etc., are all of standard pattern suitable also for rail cars and main-line locos.

North Africa: 750 h.p. Metre-Gauge Locomotive. The design of locomotives for operation on narrow-gauge railways is complicated by the loading gauge and weight restrictions. A French-built mixed-traffic locomotive for North Africa is illustrated in Fig. 156. It is carried on two three-axle bogies articulated together and fitted with buffing and drawgear. Each bogie is built up from steel plates and sections and has a cross-gangway with side-steps at the outer end. Isothermos axle-boxes are employed, each axle being driven by a self-ventilated nose-suspended traction motor.

Power is supplied by a six-cylinder supercharged Sulzer engine rated at 735 h.p. driving a main generator with overhung exciter. The compact arrangement of the engine room is demonstrated by

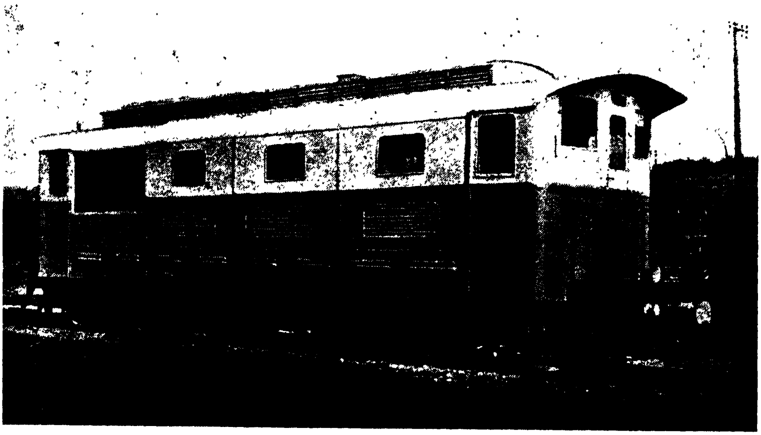


FIG. 156. Metre-gauge 735 h.p. mixed-traffic locomotive.

FIG. 157 (i). Main bogie of metre-gauge locomotive.

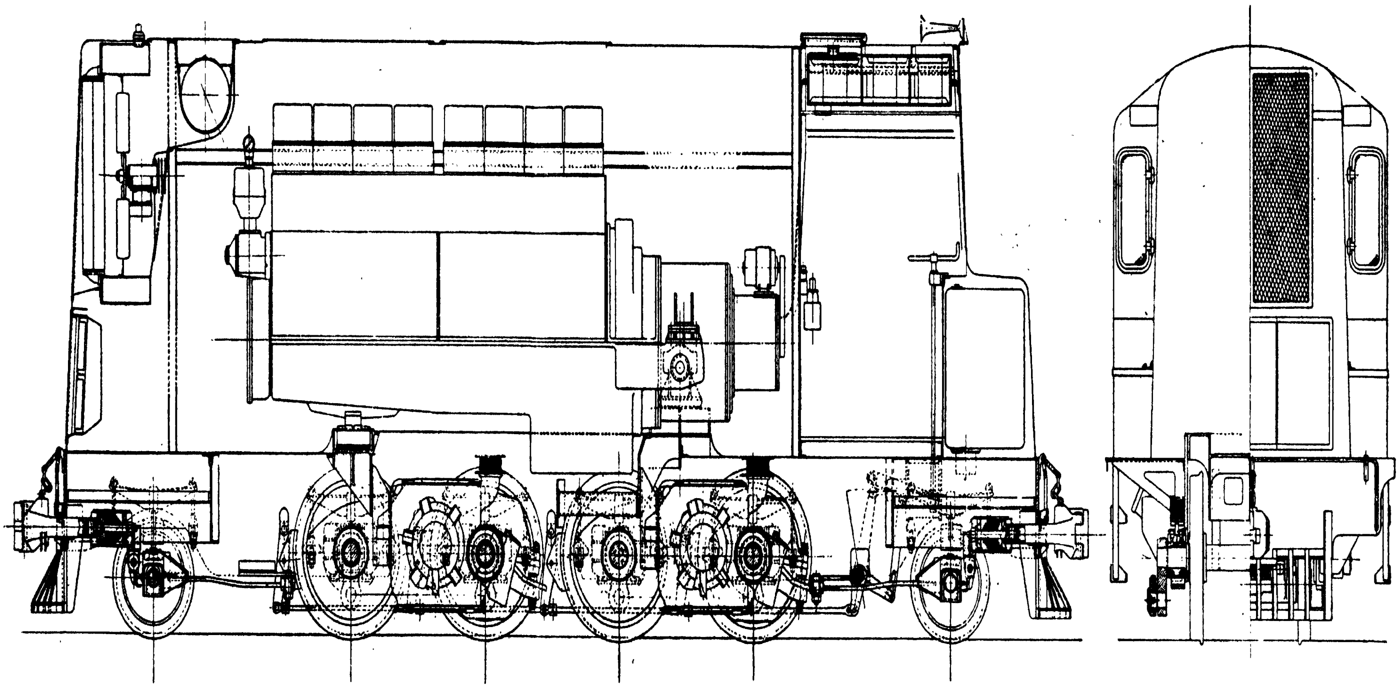


FIG. 158A. 460-500 h.p. mixed-traffic locomotive—Eastern Railway of Brazil.

158. This locomotive was built in 1939 for the Eastern Railway of Brazil and has the more unusual wheel arrangement 1–B–B–1, the four driving axles being coupled together in pairs, each pair being driven by a single nose-suspended traction motor. Two single axle guiding trucks support the outer ends of the main underframe.

The locomotive was built by the English Electric Company and follows the same general outline as their shunting and mixed-

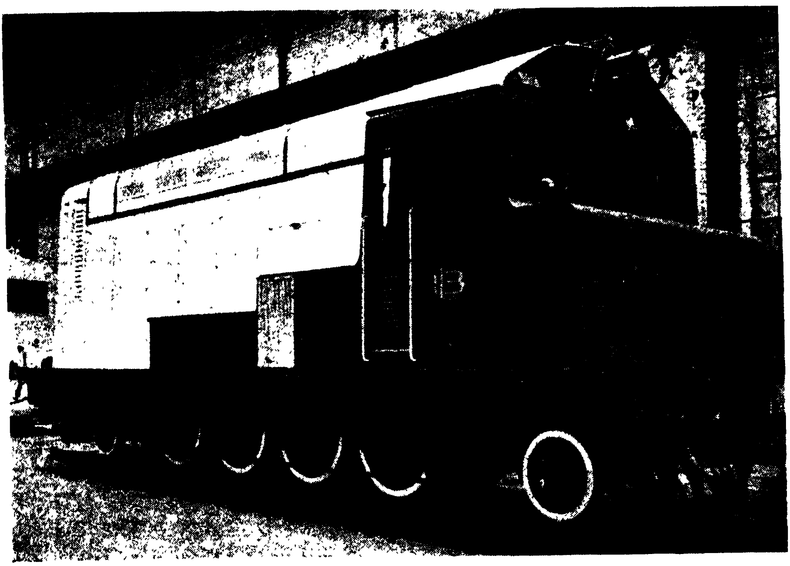
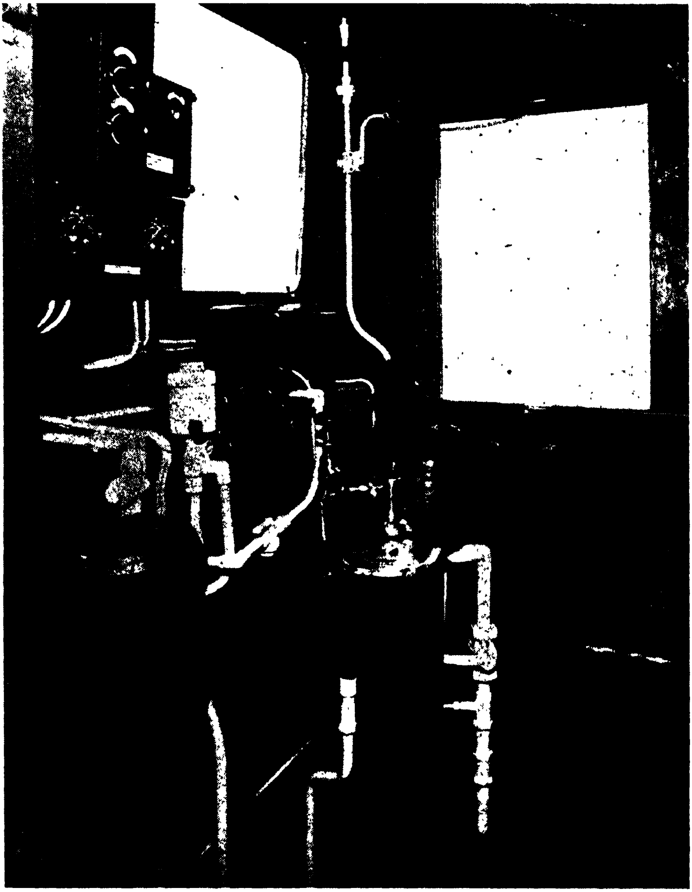


FIG. 158B. Metre-gauge 460–500 h.p. passenger locomotive.

traffic locomotives described earlier. The driving cab arrangement differs in that a single master controller is provided and the electrical equipment is built into a compartment in the engine-room bulkhead (Fig. 159).

Power is provided by an eight-cylinder engine developing 460–500 h.p. and controlled as to loading by the governor relay and vibrating contactor system. The engine and radiator compartment is arranged for access through doors from the exterior and enables the semi-streamline finish to be adopted with ample visibility for the driver. Other details are given in the Appendix, page 322.



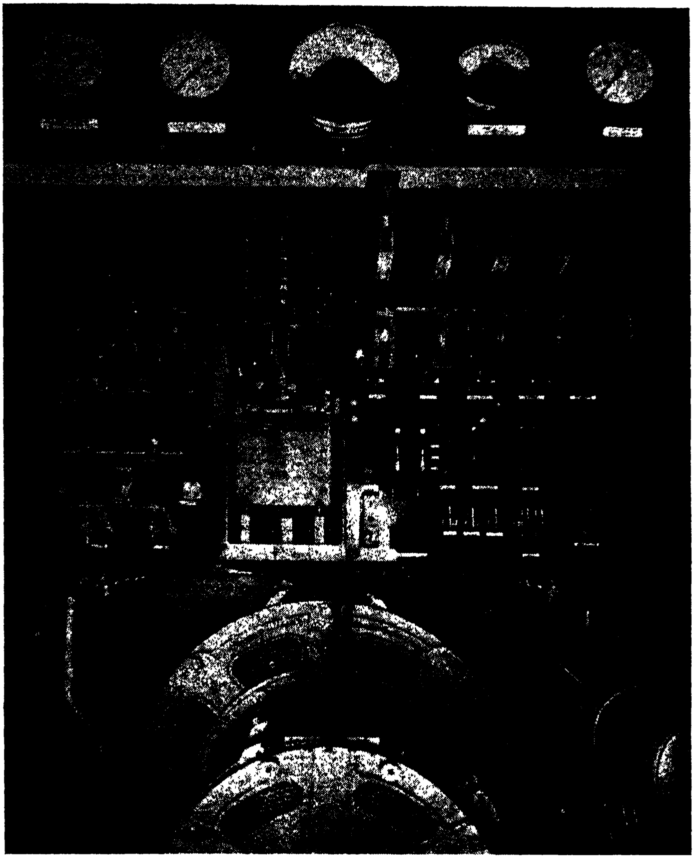
(i) Driving position.

FIG. 159. Eastern Railway of Brazil diesel-electric locomotive.

The reader will appreciate that this sequence of descriptions could be carried on for a considerable time, but the examples given serve to illustrate the various principles involved in the modern diesel-electric locomotive.

The Three-power locomotive

On page 319 in the Appendix, details are given of two types of locomotive designed to operate from any one of three sources of power. The locomotives were developed for short-distance freight and shunting work in large cities in the U.S.A. When



(ii) Electrical equipment compartment.

FIG. 159. Eastern Railway of Brazil diesel-electric locomotive.

working on the main-line they collect power in the same way as a normal direct-current locomotive but when operating in marshalling yards, factory sidings and on highways where the erection of conductor rails or overhead wires would be impossible, power is obtained from a diesel-engine-generator set connected in parallel with a battery carried on the locomotive. The battery is charged by the generator set during non-working periods and is capable of operating the locomotive with the generator cut out. Whilst quite successful in their specialized field these locomotives have now been superseded by the straight diesel-electric type.

CHAPTER TEN

TRENDS OF FUTURE DESIGN

It is always very difficult to estimate in which direction design will move with a subject such as locomotives. Some very interesting schemes come forward from time to time and two examples of these may be a pointer as to one direction in which future designs may extend. The two schemes outlined are :

(*a*) The steam-electric locomotive.

(*b*) The gas-turbine-electric locomotive.

The Steam-Electric Locomotive. Experiments with the steam-electric locomotive have been carried out in the U.S.A. where two 2500 h.p units were built in 1939 and tested on the Union Pacific Railroad. In appearance they were very similar to the modern American diesel-electric passenger locomotive, but, due to the increased weight and power, the wheel arrangement was $2\text{–}C_0 + C_0\text{–}2$, as with the larger American electric units. Both units could be operated independently or together as a single 5000 h.p. locomotive.

The method of operation is theoretically relatively simple, but has many practical difficulties. Steam is generated in an automatically-controlled oil-fired water-tube boiler with a maximum evaporation of 45,000 lbs. per hour at a pressure of 1500 lbs. per sq. in. The fuel supply is controlled by the demand on the boiler and photo-electric cells are employed to indicate normal conditions to the driver and to instigate re-ignition of the fuel, should burning cease. The steam from the boiler passes to a turbo-generator set ; thence through a large air-cooled condensor to a feed-water reservoir whence it is returned to the boiler. Six traction motors are supplied by the generator, the control system being of the diesel-electric type with various motor combinations.

The whole of the steam system, i.e. boiler, turbo-generator, condenser feed-water pump, and fuel supply, operates independently of the driver who has merely indicating lights to tell him that all is well. The weight of each unit is 265 tons and its overall length 90 feet.

The advantages claimed for a locomotive of this type are a

thermal efficiency more than double that for a normal steam locomotive, high acceleration, electric braking, elimination of corro-

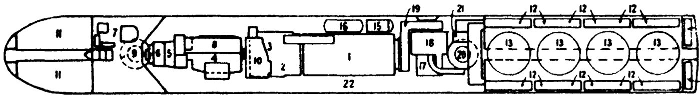


FIG. 160A. Plan and elevation of 2500 h.p. steam-electric locomotive.

1. Boiler.
2. High-pressure main turbine.
3. Low-pressure main turbine.
4. Main generator.
5. Alternator.
6. Exciter.
7. Driving position.
8. Train-heating evaporator.
9. Traction-motor blower.
10. Compressor.
11. Water-tanks.
12. Air-cooled condensers.
13. Fans.
14. Battery.
15. High-level condensate tank.
16. Feed-water heater.
17. Braking resistance.
18. Auxiliary set boiler.
19. Boiler draught fan and ducting.
20. Traction motor blower.
21. Exhaust steam header.
22. Main control gear (below frame).

sion by closed water circuit and long runs without stops for fuel and water.

The latest development in this steam-electric field are three 6000 h.p. locomotives now under construction in the U.S.A. by

FIG. 160B. 6000 h.p. non-condensing steam-turbine-electric locomotive (U.S.A.)

Baldwin-Westinghouse for the Chesapeake and Ohio Railroad, the first of which is completed. In this type a conventional locomotive boiler is used to supply steam to a non-condensing

turbine driving generators and traction motors. Coal-firing is employed and at the leading end of the locomotive is a large bunker capable of holding 29 tons of fuel. The boiler is reversed from its usual position and has its smoke-box at the rear, whilst interposed between boiler and bunker is a large totally-enclosed driving cab. Coal is fed rearwards to the firebox by a mechanical stoker and passed beneath the cab. Steam is delivered at 310 lbs. per sq. in. to a 6000 h.p. impulse-type non-condensing turbine which drives two 580 volt 2000 kw. generators at 1000 r.p.m.

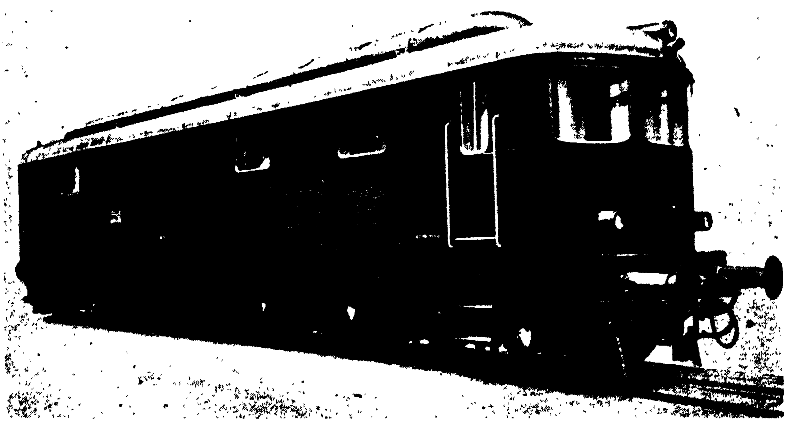


FIG. 161. Brown-Boveri $1\text{–}D_0\text{–}1$ gas-turbine locomotive—Swiss Federal Railway.

through reduction gearing. Each generator has two separate armature windings with commutators at opposite ends, so that actually there are four 1000 kw. generators. Two traction motors are connected in parallel with each generator.

The locomotive is carried on two articulated units with a leading and a central four-wheel bogie, the wheel arrangement being $2-C_01+2-C_01-B_0$. Driving wheels and those on single carrying axles are 40″ diameter. It is claimed that the locomotive is the largest and most powerful steam passenger one in the world and its leading dimensions appear to bear this out viz :

Total wheelbase 90′ 8″. Weight of locomotive alone 368 tons.

Rigid wheelbase 17′ 6″. Adhesive weight 226 tons.

Feed water is carried in a separate tender holding 25000 gallons and weighing 166 tons so that the complete machine weighs 534 tons.

The Gas-Turbine Locomotive. Fig. 161 shows a view of the Brown-Boveri built locomotive which has operated very successfully on the Swiss Federal Railways branch and local trains where electric traction is not an economical proposition. Similar in build to the diesel-electric locomotives described earlier, this locomotive has, however, a 1–D_0–1 wheel arrangement due to its greater weight, and employs a gas-turbine set as a prime-mover, driving a generator through reduction gearing. The following details are extracted by permission of British Brown-Boveri, Ltd., from their publication dealing with the locomotive. In order to be able to appreciate properly the technical considerations, it is necessary to recall first briefly the operating principle of the gas turbine, in particular that of the combustion turbine, formerly incorrectly called the constant-pressure turbine. This is best done by referring to Fig. 162, which shows diagrammatically the power unit of the gas-turbine locomotive, without the transmission system conveying the power to the driving wheels. The air, which is supplied by the compressor C in considerable excess over that required for combustion, is heated in the chamber A by the combustion of oil issuing from the burner 3. The compressed air serves to reduce the temperature of the gases to a value admissible for the blades of the gas-turbine. The gases then pass at a temperature of 850–1100°F. from the combustion chamber to the gas-turbine where they expand giving up heat for the production of mechanical work and suffering a corresponding drop in temperature. Thereupon they flow through the air pre-heater where they give up heat to the compressed air and finally escape through the roof to the atmosphere. Note that to deliver a useful output of 2000 h.p. the gas-turbine must develop an output of 8000 h.p. because the compressor absorbs 6000 h.p.

The main particulars of the Swiss Federal locomotive are given in the tables of diesel-electric locomotive, page 336. It has a guaranteed continuous turbine output to the generator of 2200 h.p. with turbine speed of 5200 r.p.m., a generator speed of 812 r.p.m. The entire thermal unit is erected on a common auxiliary

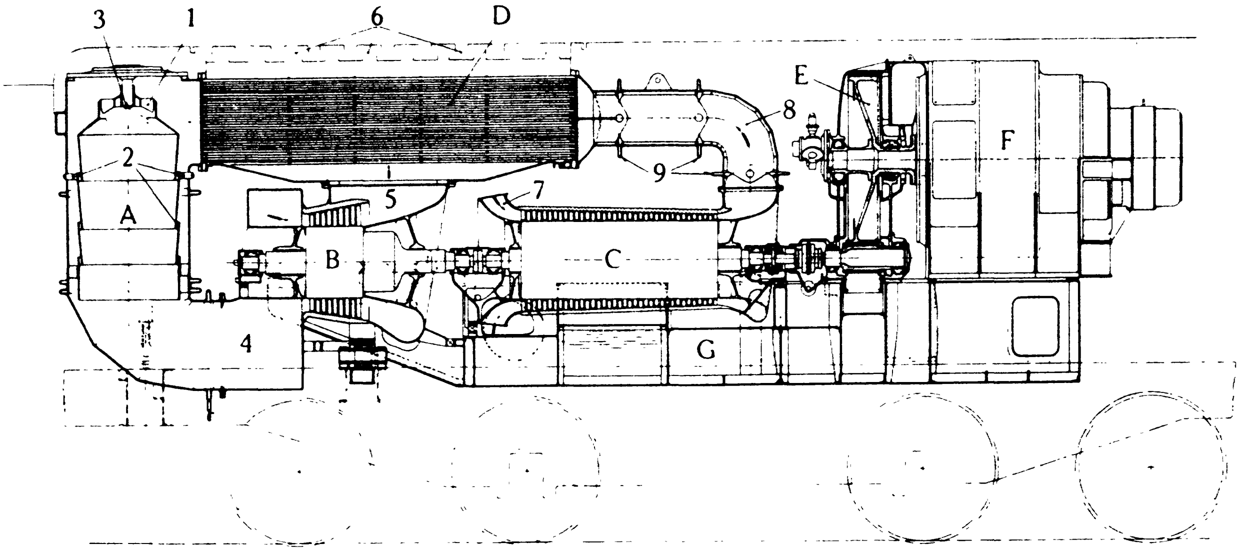


FIG. 162. Section of the gas-turbine set of the locomotive.

A. Combustion chamber. B. Gas-turbine. C. Compressor. D. Air-heater. E. Gear. F. Generator. G. Bedplate of unit.

The compressed and pre-heated air is introduced to the combustion chamber partly as combustion air through the swirl vanes (1), partly as cooling air through the slits (2). The fuel is injected through the injection nozzle (3). The combustion gas and the cooling air mix in chamber (4) and form the driving gas. The exhaust gas, which is still hot, passes into the air-heater at (5) and is exhausted to atmosphere through slits (6) in locomotive roof. The air inlet is at (7). The air outlet pipe (8) has several expansion joints (9) in order to deal with the different expansions of the gas-turbine set and the air heater.

frame which also serves as a reservoir for fuel and lubricating oil. This frame may be removed complete through a hatchway in the roof of the locomotive.

The following outline of a driver's actions when taking the locomotive into service will serve to illustrate several of the more interesting details.

On climbing into the locomotive, the driver's first duty is to start the auxiliary diesel-driven generator of 75 k.w. which serves

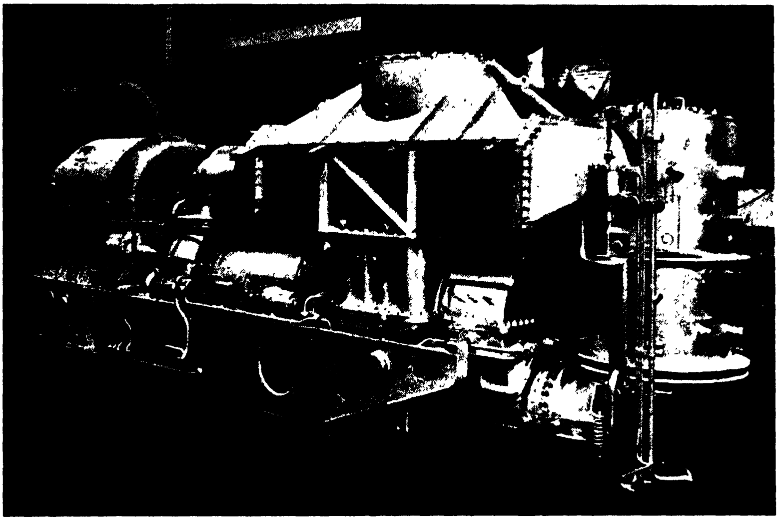


FIG. 163. Gas-turbine-generator set on the test-bed.
The whole set is mounted on a common frame which contains reservoirs for fuel and lubricating oil.

to bring the main power unit to such a speed that enough air is delivered by the compressor to permit lighting the burner. The time lapse between the starting of the auxiliary diesel set and the lighting of the burner is about 4 minutes, which the driver can use to put on his overalls. He then ignites the fuel by means of an electrically-heated ignition element, whereupon the set, now assisted by the combustion, begins to accelerate more rapidly. Returning to the driving cab (Fig. 164), he now switches over the diesel-driven generator from the generator of the gas-turbine to the driving motors, and can in this manner shunt the locomotive at a speed of about 6 to 12 miles per hour to the train without

having to use the gas-turbine set, which in the meantime continues to accelerate automatically until after a period of four minutes the normal light load speed is attained. Whilst the locomotive is

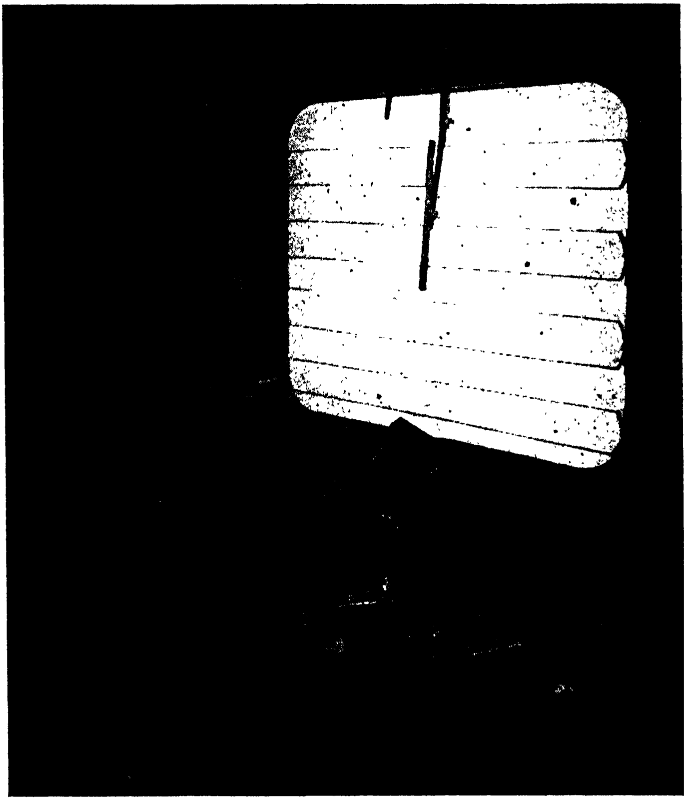


FIG. 164. Driver's cab for one-man control of the locomotive.

(*Note*: Apart from the apparatus for railway service proper, the driver can supervise without difficulty the operation of the gas-turbine.)

being coupled to the train, the driver shuts down the auxiliary diesel engine unit and switches the driving motors over to the main generator.

A small storage battery which is used to start the diesel engine supplies the requirements of the auxiliary services up to this moment. It was at first intended to make this battery large enough to serve for starting the gas-turbine. On close considera-

tion, however, this idea was abandoned, as, for frequent starting, the diesel engine appeared more reliable.

The run may now begin. The driver treads on the deadman's spring floor board, which, when released, interrupts the fuel supply and applies the compressed air brakes ; he then starts the train by gradually moving the control hand wheel through the starting notches. On approaching a rising grade for which more power is required, the driver has only to rotate his control wheel a few notches further ; the governor gear does the rest. The act of rotation of this handle feeds more fuel to the turbine set, and the servo-field regulator included in the electrical system then

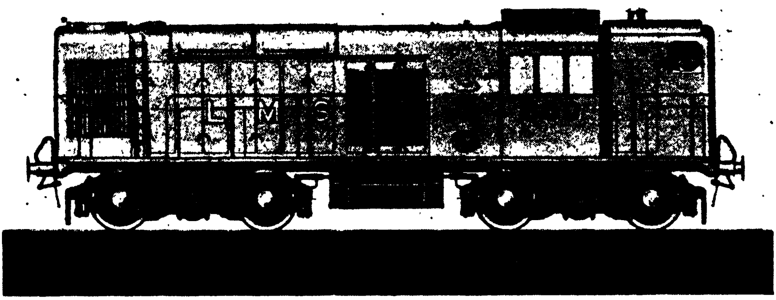


FIG. 165. Proposed 800 h.p. diesel-electric passenger locomotive—L.M.S. Railway.

adjusts the generator loading and turbine speed to the equilibrium condition.

A form of power braking can be incorporated, if desired, in which regeneration from the motors to the main generator is utilised to cause this latter to drive the compressor, an action which, as very little fuel is being supplied to the turbine, serves to absorb the returned power without the use of any additional apparatus.

No doubt to many readers the two schemes just outlined may seem rather elaborate, but that is the case with such experiments. Only experience will show whether they will be considered sufficiently economical and reliable in operation to justify their construction in bulk. Several similar schemes are under consideration by engineers of many leading manufacturers, and the

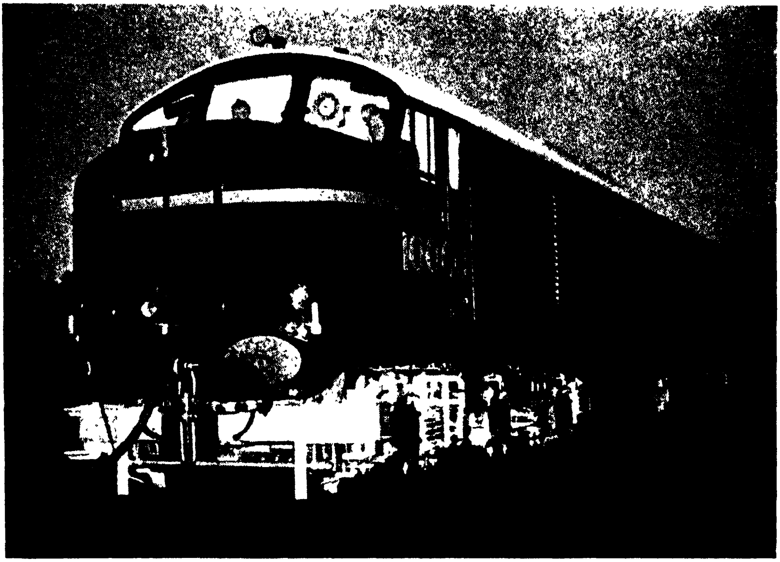


FIG. 166. 1600 h.p. main-line-diesel-electric locomotive built by L.M.S. Railway (now London Midland Region—British Railways).

FIG. 167. Main frames of British main-line diesel locomotive showing engine-generator set, radiator, water-tank, blower, etc.

next ten years should see some very interesting developments in the application of electricity to motive-power purposes.

Examples of such development in this country are recent announcements by all regions of British Railways:

The Western region has under construction an experimental 2500 h.p. gas-turbine locomotive of Brown-Boveri manufacture, somewhat larger than the Swiss machine just described.

The London Midland and Scottish regions are to carry out experimental work with 800 and 1600 h.p. diesel-electric passenger and freight locomotives.

The 800 h.p. machine (illustrated in Fig. 165) is to be used for branch-line passenger-freight and shunting duties. It is to be powered by a Paxman-Ricardo engine with B.T.H. electrical equipment.

For main-line duty the first 1600 h.p. model has recently been completed (Fig. 166). It is powered by a new 16-cylinder English Electric engine developed from that shown in Fig. 116. Two six-wheeled bogies support the main frames and each axle is driven by a nose-suspended traction motor. Roller bearings are used throughout. The compact arrangement of the engine, radiators and storage tanks on the main frame are shown in Fig. 167, and, in comparison with the standard U.S. locomotive, required very careful planning due to the much reduced loading gauge available. The design of the locomotive and the mechanical portions and erection were carried out by the railway company. A second locomotive is being constructed so that the pair may be operated as a twin-unit 3200 h.p. locomotive on the heavy Anglo-Scottish and other expresses. The Eastern and North-Eastern regions (former L.N.E.R.) also announce they intend to construct a number of similar locomotives for main-line duties, and the Southern region have a design for two 1600 h.p. locomotives carried on two four-axle bogies probably of the wheel arrangement $1 - C_0 - C_0 - 1$. This latter company in connection with its programme for complete electrification of its Eastern and Central sections is to build diesel-electric locomotives for branch line duties where electrification would not be an economic proposition.

Such developments may be the beginning of large-scale change-over to diesel-electric haulage as has already taken place in the U.S.A.

APPENDIX

I. Motor Connections

In Chapter Two various means of field connection and of armature winding are discussed. For the benefit of readers interested, certain of these are set out in the following diagrams.

II. Methods of Wheel Classification

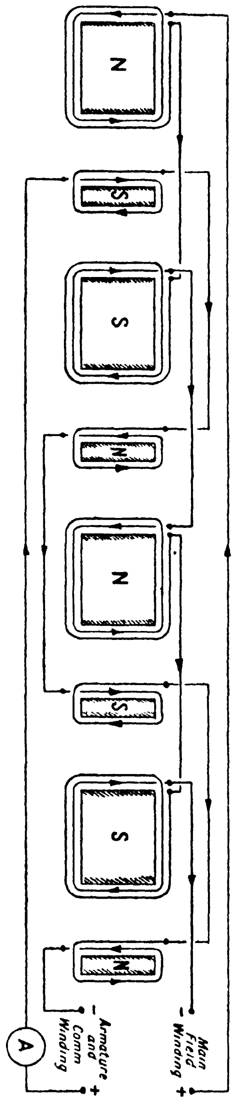
The majority of readers will be familiar with the standard method of wheel classification adopted for steam locomotives where, for example, 4–8–2 indicates a four-wheel bogie, eight driving wheels and a two-wheel trailing truck. When this method is applied to electric and diesel-electric locomotives, there is no indication as to the method and grouping of the drive and, in consequence, a number and letter system has come into use in which numbers are used to indicate carrying axles and letters to indicate driving axles, so that 4–8–2 becomes 2–D–1.

To distinguish between collective and individual axle drives, the prefix "O" is attached to examples of the latter, so that 2–D–1 indicates that the four driving axles are coupled together, and 2–D_0–1 that all axles are individually driven ; further, should the four axles be coupled in pairs, this arrangement would be designated 2–BB–1.

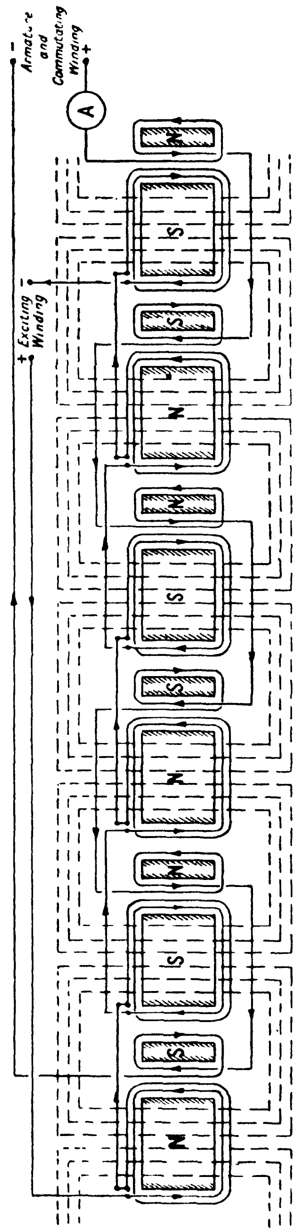
In the case of bogie and articulated locomotives, a method of indicating whether the draw-bar pull passes through a direct coupling from bogie to bogie or through the frame has been developed. In this, B_0–B_0 signifies a locomotive with two four-wheel bogies, each axle individually driven and in which the tractive pull passes through the frame. $B_0 + B_0$, however, is a similar locomotive in which the pull is exerted through an articulated joint between the bogies which also carry buffing and draw-gear at their outer ends.

Large articulated locomotives are similarly classified, e.g. 2–$D_0 + D_0$–2 signifies that two large articulated trucks are employed each having four individually-driven axles and a four-wheel guiding bogie at its outer end.

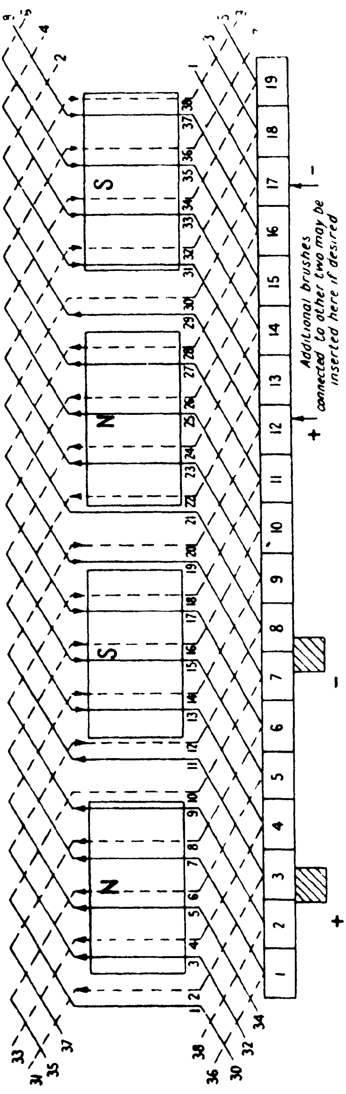
This method of axle classification is used throughout the



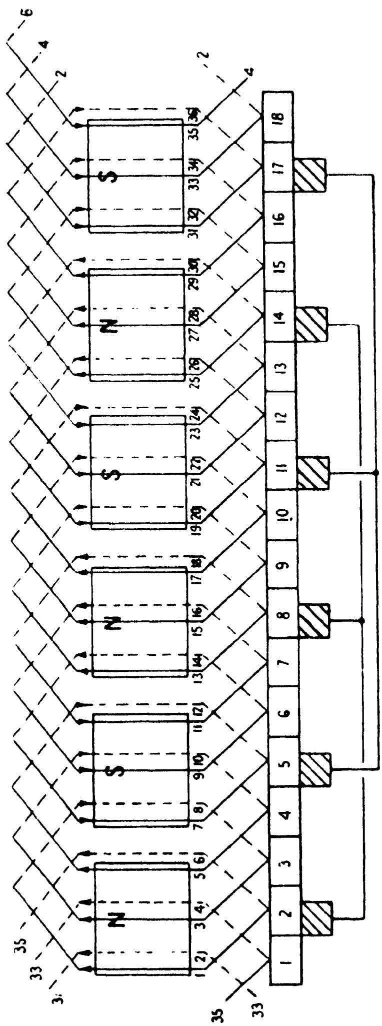
(*a*) Direct current four-pole field winding.



(*b*) Alternating current six-pole stator winding with inductive compensation.



(c) Wave-wound armature for four-pole machine.



(d) Six-pole lap-wound armature.

following tables and is invaluable in that several of the important features of the locomotive may be indicated in so simple a manner.

III. Tables

The following pages contain four sets of tables drawn up from information gathered throughout the world. These are :

(*a*) Direct-current locomotives from 1925.
(*b*) Alternating-current locomotives (Single phase) from 1925.
(*c*) Convertor type locomotives from 1925.
(*d*) " Three-power " locomotives.
(*e*) Diesel-electric locomotives from 1930.

Country	ALGERIA	BRAZIL
Railway	STATE	PAULISTA
Gauge	4′ 8½″	5′ 3″
Nominal Supply Voltage	3000	3000
Railway Type or Serial Nos.	6AE 1001 etc.	330
Makers of Mechanical Parts	Soc. d'Études.	S.L.M.
Makers of Electrical Parts		M.V.
Type of Service	Mixed	Passenger
Axle Classification	C_0+C_0	$1-C_0+C_0-1$
Year First in Service	1932	1926
Total Number in Service	30	1
Total Weight in Tons	119	99
Adhesive Weight in Tons	119	78
Weight of Mechanical Parts (tons)	64	62·8
Weight of Electrical Parts (tons)	55	36·3
Overall Length	53′ 9½″	59′ 0″
Total Wheelbase	42′ 0″	49′ 8″
Rigid Wheelbase	14′ 3″	14′ 0″
Driving Wheel Diameter	53¼″	42″
Carrying Wheel Diameter	—	36″
Traction Motors (No. and Type)	6 single-armature	6 single-armature
Motor Ventilation Details	3. 120v. motor-blowers	2. 3000v. motor-blowers
Armature Voltage	1350	1500
Total Motor Rated Horse Power — Continuous	2040	2100
Total Motor Rated Horse Power — One Hour	2400	2340
Locomotive Continuous Rating — Speed in m.p.h.	21·9	45
Locomotive Continuous Rating — Tractive Effort(lbs.)	34,400	17,500
Locomotive One-Hour Rating — Speed in m.p.h.	20·6	41·8
Locomotive One-Hour Rating — Tractive Effort(lbs.)	43,200	21,000
Maximum Tractive Effort (lbs.)	53,000	40,000
Maximum Service Speed (m.p.h.)	44	50
System of Drive	Nose-suspension	Nose-suspension
Gear Ratio	5·28	2·45
Roller Bearings used on	None	None
Mechanical Brakes	Air on loco and stock	Air on loco—Vacuum on stock
Control System—Main Circuits	E.P. contactor	E.P. contactor
Armature Combinations — Series	6 3 2	6 3 2
Armature Combinations — Parallel	– 2 3	– 2 3
Total Field Values	3 3 2	2 2 2
Economical Running Speeds	8	6
Values of Reduced Field	80% and 60%	1
Obtained by	Shunts	—
Additional Circuit Breakers	High Speed	None
Electric Braking	Regenerative	Regenerative
Excitation by	34kw. M.G. set	Genr. on blower set No. 1
Low Tension Supply	120v. 22kw. M.G. set	110v. from genr. on No. 2 blower set
Battery	60v. 120AH.	110v.
Compressors — Number and Type	2	1 reciprocating
Compressors — Motor Volts and Rating	120	110
Compressors — Capacity cu. ft./min.	40	38
Exhausters — Number and Type	—	1 rotary
Exhausters — Motor Volts and Rating	—	110
Exhausters — Capacity cu. ft./min.	—	—
Pantographs—Number and Type	2 double	2 double
Train Heating System	—	None

BRAZIL PAULISTA 5′ 3″ 3000 350 etc. A.L.C.O. G.E.	BRAZIL PAULISTA 5′ 3″ 3000 320 S.L.M. Brown-Boveri	BRAZIL PAULISTA 5′ 3″ 3000 420 etc. G.E. G.E.	BRAZIL PAULISTA 5′ 3″ 3000 381 etc. G.E. G.E.
Passenger $1-C_0+C_0-1$ 1928 5	Passenger $1-D_0-1$(1) 1929 1	Freight $1-C_0+C_0-1$ 1929 4	Passenger $2-C_0+C_0-2$ 1939 4
133 106 74·5 56·5	121·2 95·2 70·6 50·6	131·5 105·8 74·6 56·2	163 120 — —
58′ 8″ 51′ 0″ 13′ 6″ 46″ 36″	53′ 2″ 38′ 9″ 20′ 8″ 63″ 36″	58′ 8″ 51′ 0″ 13′ 6″ 46″ 36″	75′ 0″ 66′ 4″ 13′ 10″ 46″ 32″
6 single-armature Forced 1500 2405 2725	{ 8 single-armature { 4-pole 2. 1500v. motors and 4 blowers 1350 2570 3220	6 single-armature Forced 1500 2405 2725	6 single-armature 2 blowers each del. 16000 cu. ft./min. 1500 4050 4470
34·7 26,000 33·4 30,600 59,250 68	45·6 20,450 41·6 28,100 53,000 65	24·6 36,600 23·7 43,100 59,250 50	50·3 30,000 48·8 34,500 67,300 90
Nose-suspension 2·48 None Air on loco— Vacuum on stock	Buchli 3·24 None Air on loco— Vacuum on stock	Nose-suspension 3·5 None Air on loco— Vacuum on stock	Nose-suspension — Motors only Air on loco— Vacuum on stock
E.P. camshaft 6 3 2 – 2 3 3 3 3 9 2 —	E.P. camshaft 8 4 2 – 2 4 3 3 3 9 2 Tappings	E.P. camshaft 6 3 2 – 2 3 3 3 3 9 2 Shunts	E.P. contactor 6 3 2 – 2 3 3 3 3 9 2 —
High Speed Regenerative Motor-generator 65v. M.G. set 3000/1500v. motor 65v.	E.P. quick acting Regenerative M.G. set 110v. 9kw. genr. on each blower set 110v.	High Speed Regenerative 65v. M.G. set 65v. M.G. set 65v.	High Speed Regenerative Genr. on blower set 65v. M.G. set 65v.
2 reciprocating 1500 35 2 1500 80	1 reciprocating 110 30 1 110 236	2 reciprocating 1500 35 2 1500 80	2 reciprocating 1500 35 2 1500 80
2 double None	2 double None	2 double None	2 double None

Country	BRAZIL	BELGIUM
Railway	OESTE DE MINAS	Brussels-Tervueren
Gauge	3′ 3⅜″	4′ 8½″
Nominal Supply Voltage	1500	1500
Railway Type or Serial Nos.	400 etc.	BTL 1
Makers of Mechanical Parts	M.V.	Charleroi
Makers of Electrical Parts	M.V.	Charleroi
Type of Service	Mixed	Mixed
Axle Classification	B_0+B_0	B_0+B_0
Year First in Service	1927	1936
Total Number in Service	5	1
Total Weight in Tons	47	62
Adhesive Weight in Tons	47	62
Weight of Mechanical Parts (tons)	29	—
Weight of Electrical Parts (tons)	18	—
Overall Length	36′ 6″	—
Total Wheelbase	24′ 11½″	—
Rigid Wheelbase	7′ 10½″	—
Driving Wheel Diameter	43″	—
Carrying Wheel Diameter	—	—
Traction Motors (No. and Type)	4 single-armature	4 twin-armature
Motor Ventilation Details	Forced	Self
Armature Voltage	750	750
Total Motor Rated Horse Power — Continuous	448	785
Total Motor Rated Horse Power — One Hour	640	1000
Locomotive Continuous Rating — Speed in m.p.h.	14·9	—
Locomotive Continuous Rating — Tractive Effort (lbs.)	11,200	—
Locomotive One-Hour Rating — Speed in m.p.h.	15·1	—
Locomotive One-Hour Rating — Tractive Effort (lbs.)	14,990	—
Maximum Tractive Effort (lbs.)	26,400	34,700
Maximum Service Speed (m.p.h.)	31	43
System of Drive	Nose-suspension	Sécheron quill&Spring
Gear Ratio	4·32 Pass. 5·32 Freight	—
Roller Bearings used on	—	Armatures
Mechanical Brakes	Air on loco—Vacuum on stock	Air on loco and stock
Control System—Main Circuits	E.P. contactors	E.P. contactors
Armature Combinations — Series	4 2	8 4 2
Armature Combinations — Parallel	– 2	– 2 4
Total Field Values	2 2	1 1 1
Economical Running Speeds	4	3
Values of Reduced Field	1	None
Obtained by	tappings	—
Additional Circuit Breakers	None	Fitted
Electric Braking	Regenerative	None
Excitation by	28kw. genr. on blower set	—
Low Tension Supply	16kw. genr. on blower set	36v.
Battery	105	Nickel-Cadmium
Compressors — Number and Type	1 reciprocating	2
Compressors — Motor Volts and Rating	105	—
Compressors — Capacity cu. ft./min.	25	—
Exhausters — Number and Type	1	—
Exhausters — Motor Volts and Rating	—	—
Exhausters — Capacity cu. ft./min.	—	—
Pantographs—Number and Type	1 double	2 single
Train Heating System	None	—

CANADA Har. Com. Montreal 4′ 8½″ 2400 101 etc. B.P. E.E.Co.	CHILE TRANS-ANDEAN 3′ 3⅜″ 3000 S.L.M. Brown-Boveri	CZECHOSLOVAKIA STATE 4′ 8½″ 1500 E465-01 etc. C.K.D. Brown-Boveri	CZECHOSLOVAKIA STATE 4′ 8½″ 1500 E466-01 etc. Skoda Skoda
Freight $B_0 + B_0$ 1925 9	Mixed 1 – C + C – 1 1927 3	Passenger $1 - D_0 - 1^{(1)}$ 1927 2	Passenger $1 - D_0 - 1^{(1)}$ 1927 3
99 99 66 33	85·6 72·3 52·7 32·9	76·8 57·5 52·2 24·6	84 65 48 36
40′ 0″ 28′ 0″ 9′ 3″ 50″ —	52′ 10″ 42′ 10″ — 39¾″ 28″	42′ 6″ 32′ 2″ 5′ 11″ 64″ 40″	47′ 6″ 35′ 6″ 7′ 10″ 58¾″ 40″
4 single-armature 1 2400v. 50 h.p. motor and 2 blowers 1200 1400 1720	4 adhesion, 2 rack Self 1500 1568 1890	4 single-armature Forced 675 1200 1450	4 twin-arm. 4-pole 1. 13·5 h.p. motor with two blowers each 8000 c.f.m. 675 1300 1575
16·3 32,000 15·3 42,000 70,000 25	(Adhesion) (Rack) — — 17·4 8·7 — — 35,250 70,500 24·8 9·9	33·3 13,100 31 17,200 30,000 56	33·9 14,300 31·2 18,950 33,900 56
Nose-suspension 5·67 None Air on loco and stock	Geared siderod 4·67 8·13 None Air on loco and stock	Buchli 3·205 None Air on loco and stock	Skoda quill and link 3·65 None Air on loco and stock
Motor camshaft 4 2 – 2 1 1 2 None —	Motor camshaft 4 2 4 2 – 2 2 1 1 1 2 1 None None —	E.P. camshaft 4 2 – 2 1 2 3 1 —	Motor camshaft 4 2 – 2 1 4 5 to 33% in 3 steps —
Fitted None — 120v. 16kw. genr. on blower set None	None Rheostatic From O/H line 36v. 36v. 100AH.	Fitted None — — —	Fitted None — 60v. 3·5kw. M.G. set 60v.
2 reciprocating 120 50 — — —	2 — — — — —	1 rotary — — 1 rotary — —	1 reciprocating 1500v. 16 h.p. — — — —
2 double None	2 single None	2 double —	2 double —

Country	CZECHOSLOVAKIA	CZECHOSLOVAKIA
Railway	STATE	STATE
Gauge	4′ 8½″	4′ 8½″
Nominal Supply Voltage	1500	1500
Railway Type or Serial Nos.	E423-01,02	E467-04 etc.
Makers of Mechanical Parts	Adamsthal	Skoda
Makers of Electrical Parts	M.V.	Skoda
Type of Service	Shunting	Passenger
Axle Classification	$B_0 - B_0$	$1 - D_0 - 1^{(1)}$
Year First in Service	1927	1930
Total Number in Service	2	2
Total Weight in Tons	52	84
Adhesive Weight in Tons	52	65
Weight of Mechanical Parts (tons)	30	48
Weight of Electrical Parts (tons)	22	36
Overall Length	37′ 4″	47′ 6″
Total Wheelbase	24′ 7″	35′ 6″
Rigid Wheelbase	7′ 0″	7′ 10″
Driving Wheel Diameter	38″	58¾″
Carrying Wheel Diameter	—	40″
Traction Motors (No. and Type)	4 Single-armature	4 twin-arm. 4-pole
Motor Ventilation Details	1 motor-blower set	1. 13·5 h.p. motor with two blowers each 8000. c.f.m
Armature Voltage	675	675
Total Motor Rated Horse Power — Continuous	760	1300
Total Motor Rated Horse Power — One Hour	1000	1575
Locomotive Continuous Rating — Speed in m.p.h.	22·1	33·9
Locomotive Continuous Rating — Tractive Effort (lbs.)	12,800	14,300
Locomotive One-Hour Rating — Speed in m.p.h.	19·6	31·2
Locomotive One-Hour Rating — Tractive Effort (lbs.)	19,400	18,950
Maximum Tractive Effort (lbs.)	29,100	33,900
Maximum Service Speed (m.p.h.)	45	56
System of Drive	Nose-suspension	Skoda quill & link
Gear Ratio	4·31	3·65
Roller Bearings used on	None	motors
Mechanical Brakes	Air on loco and	all rolling stock
Control System—Main Circuits	E.P. contactor	E.P. camshaft
Armature Combinations — Series	4 2	4 2
Armature Combinations — Parallel	– 2	– 2
Total Field Values	2 2	1 4
Economical Running Speeds	4	5
Values of Reduced Field	1	82·5% 57·5% 40%
Obtained by	Tappings	—
Additional Circuit Breakers	None	High Speed
Electric Braking	None	None
Excitation by	—	—
Low Tension Supply	Gen. on blower set	50v. from battery
Battery	—	Charged in series with auxiliaries
Compressors — Number and Type	1	1. 2-stage rotary
Compressors — Motor Volts and Rating	—	1500v. 20 h.p.
Compressors — Capacity cu. ft./min.	—	70
Exhausters — Number and Type	—	—
Exhausters — Motor Volts and Rating	—	—
Exhausters — Capacity cu. ft./min.	—	—
Pantographs—Number and Type	1 double	2 double
Train Heating System	None	—

FRANCE PARIS-ORLEANS-MIDI 4′ 8½″ 1350v. E401 E402 Ganz Ganz	FRANCE PARIS-ORLEANS-MIDI 4′ 8½″ 1350v. E601 Thomson, Schneider, Jeumont	FRANCE PARIS-ORLEANS-MIDI 4′ 8½″ 1350v. E501 E502 S.L.M. Brown-Boveri	FRANCE PARIS-ORLEANS-MIDI 4′ 8½″ 1350v. E503 etc. Cie F.L. Cie E.M.
Express $2-B-B-2$ 1925 1 1	Express $2-C_0+C_0-2$ 1925 1	Express $2-D_0-2$ 1926 1 1	Express $2-D_0-2$ 1933 43
128 130 70·9 70·9 58 58 69·8 71·8	116 73·2 69·8 46·3	119 123 70·9 70·9 73·3 73·3 45·7 50·5	138·8 78·7 89 49
52′ 6″ 43′ 0″ 18′ 5″ 69″ 38″	62′ 3″ 53′ 2″ 9′ 4″ 47″ 38″	58′ 4″ 46′ 5½″ 18′ 10″ 69″ 38″	58′ 4″ 47′ 3″ 19′ 10″ 69″ 38″
4 single-arm. 8-pole 2. 110v. 20 h.p. motor-blowers each 9000 c.f.m. 1350 3335 3550 4145 4340	6 single-arm. 2-pole 2. 1350v. 22 h.p. motors 6. blowers each 3000 c.f.m. 675 2020 2960	4 single-arm. 6-pole 2.1350v. 20 h.p motors 4 blowers each 4250 c.f.m. 1350 3155 3550	4 single-arm. 6-pole 4. 1350v. motor-blower sets each 4250 c.f.m. 1350 3265 3650
43·5 44·3 28,650 30,000 40·7 42·2 37,950 38,800 47,500 75	56·8 13,450 54·0 20,500 48,500 75	42·2 41·4 28,000 28,650 40·7 39·6 32,600 33,500 47,500 81	44·7 27,450 42·9 31,800 53,000 81
Kando rod None None Air	Armatures mounted on axles "Gearless" None on locomotives	Buchli on both wheels per axle 2·42 None and on rolling	Buchli on both wheels per axle 2·42 None stock
E.M.&E.P. line switches 4 2 1 4 2 1 – 2 4 – 2 4 3 3 3 5 5 3 9 13 79% 59% 79,59,39,29% —	E.P. contactor 6 3 2 – 2 3 3 3 2 8 75% 50% Tappings	E.P. contactor 4 2 – 4 2 – – 2 4 – 2 4 4 4 3 5 5 3 11 13 4 (min. 26%) Tapps. and shunts	E.P. contactor 4 2 – – 2 4 6 6 5 17 5 (min. 26%) Tapps. and shunts
None None — 2 110v. 30kw. M.G. set None	High Speed None — 72v. from battery 72v. 72AH.*	High Speed Regen. on E502 50kw. 100v. M.G. set 72v. 2kw. M.G. set 72v. 72AH.	High Speed Regenerative 100v. 50kw. M.G. set 72v. from battery 72v. 72AH.*
2 two-cylinder 1350v. 11 h.p. 60 — — —	2 two-cylinder 1350v. 17·5 h.p. 75 — — —	2 two-cylinder 1350v. 11 h.p. 60 — — —	2 1350v. 45 — — —
2 double at 1350v.	2 single at 1350v.	2 single at 1350v.	2 single at 1350v.

* Charged in series with auxiliaries.

Country	FRANCE	FRANCE
Railway	PARIS-ORLEANS-MIDI	PARIS-ORLEANS-MIDI
Gauge	4′ 8½″	4′ 8½″
Nominal Supply Voltage	1350v.	1350v.
Railway Type or Serial Nos.	E701 etc.	E703
Makers of Mechanical Parts	Batignolles	Alsthom
Makers of Electrical Parts	Oerlikon	Alsthom
Type of Service	Express	Express
Axle Classification	$2-D_0-2$	$2-D_0-2$
Year First in Service	1935	1935
Total Number in Service	2	1
Total Weight in Tons	134·3	137
Adhesive Weight in Tons	78·7	77·6
Weight of Mechanical Parts (tons)	85·5	81
Weight of Electrical Parts (tons)	47·0	53
Overall Length	58′ 4″	58′ 4″
Total Wheelbase	47′ 3″	47′ 3″
Rigid Wheelbase	19′ 10″	19′ 10″
Driving Wheel Diameter	69″	69″
Carrying Wheel Diameter	38″	38″
Traction Motors (No. and Type)	4 twin-armature 6-pole	2 triple-arm. 6-pole
Motor Ventilation Details	2. 1350v. sets each 10,500 c.f.m.	6. 675v. motor blower sets each 3500 c.f.m.
Armature Voltage	675	675
Total Motor Rated Horse Power — Continuous	3580	3550
Total Motor Rated Horse Power — One Hour	4110	4045
Locomotive Continuous Rating — Speed in m.p.h.	49·5	47·3
Locomotive Continuous Rating — Tractive Effort (lbs.)	27,100	26,750
Locomotive One-Hour Rating — Speed in m.p.h.	46·7	45·2
Locomotive One-Hour Rating — Tractive Effort (lbs.)	33,000	33,400
Maximum Tractive Effort (lbs.)	53,000	53,000
Maximum Service Speed (m.p.h.)	81	81
System of Drive	Oerlikon quill and Oldham coupling	Quill and link
Gear Ratio	3·55	3·48
Roller Bearings used on	None	None
Mechanical Brakes	Air on locomotives and rolling stock	
Control System—Main Circuits	E.P. contactor	E.P. contactor
Armature Combinations — Series	8 4 2	6 3 2
Armature Combinations — Parallel	– 2 4	– 2 3
Total Field Values	5 5 5	4 4 3
Economical Running Speeds	15	11
Values of Reduced Field	4	3
Obtained by	Tapps and shunts	Tapps. and shunts
Additional Circuit Breakers	None	None
Electric Braking	Regenerative	Regenerative
Excitation by	40v. 38kw. M.G. set	47v. 34·5kw. M.G. set
Low Tension Supply	72v. from battery	72v. from battery
Battery	72v7.2AH. charged in series with aux.	72v.72AH. charged in series with aux.
Compressors — Number and Type	2	2 reciprocating
Compressors — Motor Volts and Rating	1350v.	1350v. 12 h.p.
Compressors — Capacity cu. ft./min.	45	45
Exhausters — Number and Type	—	—
Exhausters — Motor Volts and Rating	—	—
Exhausters — Capacity cu. ft./min.	—	—
Pantographs—Number and Type	2 single	2 single
Train Heating System	at 1350v.	at 1350v.

FRANCE PARIS-ORLEANS-MIDI 4′ 8½″ 1350v. E704 Schneider Jeumont	FRANCE PARIS-ORLEANS-MIDI 4′ 8½″ 1350v. E1 etc. Thomson, Schneider, Jeumont	FRANCE PARIS-ORLEANS-MIDI 4′ 8½″ 1350v. E101, E171 etc. Batignolles Oerlikon	FRANCE PARIS-ORLEANS-MIDI 4′ 8½″ 1350v. E201, E205, E221etc. Soc. Alsacienne
Express $2 - D_0 - 2$ 1935 1	Mixed $B_0 - B_0$ 1925 80	Mixed $B_0 - B_0$ 1925 70 10	Mixed $B_0 - B_0$ 1925 4 16 4
134·5 79·6 89·5 44·7	68 68 40 28	75·5 75·5 44 31·5	76 76·5 76 76 76·5 76 45 (approx.) 31·5 (approx.)
58′ 4″ 47′ 3″ 19′ 10″ 69″ 38″	41′ 7″ 28′ 10″ 8′ 10″ 49¼″ —	41′ 3″ 28′ 7½″ 9′ 2½″ 53¼″ —	42′ 11″ 27′ 10″ 9′ 2½″ 53¼″ —
4 twin-arm. 4-pole 2. 675v. motor-blower sets each 6600 c.f.m. 675 3550 4045	4 single-arm. 4-pole 2. 1350v. 8 h.p. motor-blower sets each 2450 c.f.m. 1350 1300 1620	4 single-arm. 4-pole 2. 1350v. 11 h.p. motor-blower sets each 5000 c.f.m. 1350 1520 1695	4 single-arm. 4-pole 2. 1350v. 17·5 h.p. motor-blower sets each 3900 c.f.m. 1350 1225 1300 1225 1400 1660 1400
48·4 27,600 46·5 32,450 53,000 81	28·6 17,100 26·7 22,700 46,200 56	29·8 37·9 19,100 15,050 29·2 37·2 21,800 17,100 50,600 56 65	28·9 29·5 20·8 15,850 16,550 22,050 27·2 27·3 20·8 19,400 22,700 27,000 50,600 56 56 37
Quill and cup 3·38 motors Air	Nose-suspension 3·1 None on locomotives	Nose-suspension 3·47 2·68 None and rolling	Nose-suspension 3·14 to 4·35 None stock
E.P. contactor 8 4 2 – 2 4 5 5 5 15 4 Tapps. and shunts	E.P. contactor 4 2 – – 2 4 3 3 3 9 72% and 57% Shunts	E.P. contactor 4 2 – – 2 4 3 3 3 9 75% and 50% Tappings	E.P. contactor 4 2 – – 2 4 3 3 3 9 78% and 60% —
None Regenerative Two 45v. 22kw. M.G. sets 72v. from battery 72AH.*	None None — 32v. from battery 72AH.* * Charged in seri	None None — 32v. from battery 72AH.* es with auxiliaries	None None — 32v. from battery 32v. 72AH.*
2 1350v. 12 h.p. 45 — — —	2 two-cylinder 1350v. 12 h.p. 44 — — —	2 two-cylinder 1350v. 50 — — —	2 1350v. 12 h.p. 44 — — —
2 single at 1350v.	2 double at 1350v.	2 double at 1350v.	2 double at 1350v.

Country	FRANCE	FRANCE
Railway	PARIS-ORLEANS-MIDI	PARIS-ORLEANS-MIDI
Gauge	4′ 8½″	4′ 8½″
Nominal Supply Voltage	1350	1500
Railway Type or Serial Nos.	E225 etc.	E3101 etc.
Makers of Mechanical Parts	C.E.F.	Alsthom
Makers of Electrical Parts	C.E.F.	Alsthom
Type of Service	Mixed	Express
Axle Classification	$B_0 + B_0$	$2 - C_0 - 2$
Year First in Service	1925	1925
Total Number in Service	16	10
Total Weight in Tons	73·5	104
Adhesive Weight in Tons	73·5	56
Weight of Mechanical Parts (tons)	43·5	—
Weight of Electrical Parts (tons)	30	—
Overall Length	41′ 9½″	47′ 6½″
Total Wheelbase	27′ 10″	36′ 9″
Rigid Wheelbase	9′ 2½″	13′ 2″
Driving Wheel Diameter	53½″	69″
Carrying Wheel Diameter	—	—
Traction Motors (No. and Type)	4 single-arm. 4-pole	3 vertical twin-arm. 4-pole
Motor Ventilation Details	2. 1350v. 17·5 h.p. motor-blower sets each 3900 c.f.m.	2 motor-blower sets each 4600 c.f.m.
Armature Voltage	1350	500
Total Motor Rated Horse Power — Continuous	1225	1480
Total Motor Rated Horse Power — One Hour	1400	2070
Locomotive Continuous Rating — Speed in m.p.h.	28·9	52·7
Locomotive Continuous Rating — Tractive Effort (lbs.)	15,850	10,500
Locomotive One-Hour Rating — Speed in m.p.h.	27·2	48·4
Locomotive One-Hour Rating — Tractive Effort (lbs.)	19,400	15,000
Maximum Tractive Effort (lbs.)	49,500	—
Maximum Service Speed (m.p.h.)	56	—
System of Drive	Nose-suspension	Twin bev. quill & spgs.
Gear Ratio	3·45	3·5
Roller Bearings used on	None	Motor thrust bear.
Mechanical Brakes	Air on loco and rolling stock	Air on loco and rolling stock
Control System—Main Circuits	E.P. contactor	Motor camshaft
Armature Combinations — Series	4 2 –	6 3
Armature Combinations — Parallel	– 2 4	– 2
Total Field Values	3 3 3	4 4
Economical Running Speeds	9	8
Values of Reduced Field	80% and 60%	3
Obtained by	—	Shunts
Additional Circuit Breakers	None	High Speed
Electric Braking	None	None
Excitation by	—	—
Low Tension Supply	32v. from battery	From battery
Battery	32v. 72AH.*	Charged from line thro' series resistance
Compressors — Number and Type	2	2 2-cylinder
Compressors — Motor Volts and Rating	1350v. 12 h.p.	1500v. 20 h.p.
Compressors — Capacity cu. ft./min.	44	50
Exhausters — Number and Type	—	—
Exhausters — Motor Volts and Rating	—	—
Exhausters — Capacity cu. ft./min.	—	—
Pantographs—Number and Type	2 double	3 double
Train Heating System	at 1350v.	at 1500v.

France Paris-Orleans-Midi 4′ 8½″ 1500 E4801 etc. C.E.F. Alsthom	France Paris-Orleans-Midi 4′ 8½″ 1500 E4501, E4001 etc. — —	France Paris-Orleans-Midi 4′ 8½″ 1500 E4598 etc. — —	France Paris-Orleans-Midi 4′ 8½″ 1500 E4601, E4101 etc. C.E.F. C.E.F.
Express $2 - D_0 - 2$ 1932 42	Passenger Freight $B_0 + B_0$ 1925 49 40	Passenger $B_0 + B_0$ 1930 3	Passenger Mixed $B_0 + B_0$ 1928 50 90
120·6 75·2 71·2 49·4	70·8 73 70·8 73 — —	74·8 74·8 42·3 32·5	76·6 76·6 43·3 33·3
55′ 2½″ 45′ 6″ 20′ 8″ 69″ 35½″	38′ 11″ 27′ 5″ 9′ 5½″ 55¼″ —	38′ 11″ 27′ 5″ 9′ 5½″ 55¼″ —	42′ 2½″ 29′ 3½″ 9′ 8″ 55¼″ —
4 twin-arm. 4-pole 2. 1500v. motor blowers each 10,600 c.f.m. 750 3550 3850	4 single-arm. 4-pole 2. 1500v. motors with 4 blowers each 2100 c.f.m. 1500 985 1380	4 single-arm. 4-pole 2. 1500v. motors with 4 blowers each 2100 c.f.m. 1500 1560 1755	4 single-arm. 4-pole 2. 1500v. motors with 4 blowers each 2800 c.f.m. 1500 1560 1755
52·2 25,550 50·5 28,200 53,000 75	31·7 19·6 11,450 18,050 28·6 17·7 17,600 26,450 47,500 56 43	27·3 21,200 26·1 25,050 50,500 56	27·3 19·4 21,200 30,400 26·1 18·5 25,050 35,700 51,500 56 43·5
Quill and Spring 4·82 None Air on loco and rolling stock	Nose-suspension 3·14 5·066 None Air on loco and rolling stock	Nose-suspension 3·475 None Air on loco and rolling stock	Nose-Suspension 3·475 4·875 None Air on loco and rolling stock
E.P. contactor 8 4 2 — 2 4 4 4 3 11 3 Tapps. and shunts	Motor camshaft 2 — 2 4 3 3 6 2 Tappings	Motor camshaft 2 — 2 4 3 3 6 2 Tappings	E.P. contactor 4 2 — — 2 4 3 3 3 9 2 Tappings
High Speed None — 72v. from battery 72v. 85A.H.*	High Speed Regen. & rheostatic 50v. 22·5kw. genr. on M.G. set 120v. from 14kw. M.G. set 40v.	High Speed Regenerative 50v. 22·5kw. genr. on M.G. set 40v. from battery 40v.	High-Speed Rheostatic — 72v. from battery 72v. 85AH.*
2 two-cylinder 1500v. 20 h.p. 50 — — —	1 2 120v. 120v. 1500v. 64 64 85 — — —	1 120v. 64 — — —	2 1500v. 50 — — —
2 double at 1500v.	2 double at 1500v.	2 double at 1500v.	2 double 1500v.

* Charged in series with auxilliaries.

Country	FRANCE	FRANCE
Railway	PARIS-ORLEANS-MIDI	P.L.M.
Gauge	4′ 8½″	4′ 8½″
Nominal Supply Voltage	1500	1500 o/h trolley wire and third rail
Railway Type or Serial Nos.	E4701 etc. E4201 etc.	262AE.1. etc.
Makers of Mechanical Parts	Alsthom	Batignolles
Makers of Electrical Parts	Alsthom	Oerlikon
Type of Service	Passenger, Mixed	Express
Axle Classification	$B_0 + B_0$	$2 - C_0 + C_0 - 2$
Year First in Service	1934	1929
Total Number in Service	17 50	4
Total Weight in Tons	78·6	156·5
Adhesive Weight in Tons	78·6	105·7
Weight of Mechanical Parts (tons)	44·2	102
Weight of Electrical Parts (tons)	34·4	52·9
Overall Length	42′ 2½″	78′ 0″
Total Wheelbase	29′ 3½″	68′ 3″
Rigid Wheelbase	9′ 8″	15′ 1″
Driving Wheel Diameter	55¼″	63″
Carrying Wheel Diameter	—	39⅜″
Traction Motors (No. and Type)	4 single-arm. 4-pole	6 twin-arm. 4-pole
Motor Ventilation Details	2. 1500v. motors with 4 blowers each 2800 c.f.m.	Forced
Armature Voltage	1500	500
Total Motor Rated Horse Power — Continuous	1560	4115
Total Motor Rated Horse Power — One Hour	1755	5270
Locomotive Continuous Rating — Speed in m.p.h.	27·3 19·4	54
Locomotive Continuous Rating — Tractive Effort (lbs.)	21,200 30,400	28,600
Locomotive One-Hour Rating — Speed in m.p.h.	26·1 18·5	49·7
Locomotive One-Hour Rating — Tractive Effort (lbs.)	25,050 35,700	39,700
Maximum Tractive Effort (lbs.)	53,000	57,400
Maximum Service Speed (m.p.h.)	56 43	68
System of Drive	Nose-suspension	Quill & spring-link
Gear Ratio	3·475 4·875	3·185
Roller Bearings used on	None	None
Mechanical Brakes	Air on loco and rolling stock	Air on loco and rolling stock
Control System—Main Circuits	E.P. contactor	E.P. contactor*
Armature Combinations — Series	4 2 –	12 6 4 3
Armature Combinations — Parallel	– 2 4	– 2 3 4
Total Field Values	3 3 3	3 3 3 3
Economical Running Speeds	9	12
Values of Reduced Field	2	70% and 55%
Obtained by	tappings	shunts
Additional Circuit Breakers	High Speed	None
Electric Braking	Regen. & rheostatic	None
Excitation by	124v. 40kw. M.G. set	—
Low Tension Supply	72v. from battery	64v. from battery
Battery	72v.85AH charged in series with aux.	Charged in series with auxilliaries
Compressors — Number and Type	2	2 two-cylinder
Compressors — Motor Volts and Rating	1500v.	1500v.
Compressors — Capacity cu. ft./min.	85	46
Exhausters — Number and Type	—	—
Exhausters — Motor Volts and Rating	—	—
Exhausters — Capacity cu. ft./min.	—	—
Pantographs—Number and Type	2 double	2 double
Train Heating System	1500v.	None

* With E.P. camshaft groups for motor combination and braking.

FRANCE	FRANCE	FRANCE	FRANCE
PAR	IS - LYONS-MEDITER	RANEAN	S.N.C.F.†
4′ 8½″	4′ 8½″	4′ 8½″	4′ 8½″
1500v. on o	verhead trolley wire	and third rail	1500
161.BE.1 etc.	161.CE.1 etc.	161.DE.1 etc.	501 etc.
Schneider	Soc. Alsaciennes	Cie F.L.	Cie F.L.
Alsthom	C.E.F.	Cie E.M.	Cie E.M.
Freight	Freight	Freight	Express
$1-A+B_0+B_0+A-1$	$1-C_0+C_0-1$	$1-C_0+C_0-1$	$2-D_0+2$
1929	1929	1926	1937
10	10	10	23
126·2	125·6	127·5	128
102·2	105	108·7	79
—	—	—	79
—	—	—	47·5
67′ 6″	69′ 6½″	70′ 10½″	58′ 4″
57′ 3″	58′ 6″	57′ 6″	47′ 3″
9′ 8″	16′ 2″	14′ 2½″	19′ 10½″
49¼″	55¼″	56¾″	69″
36″	34″	39¾″	38″
6 single-arm. 4-pole 2. 1500v. 11 h.p. motor-blower sets each 3900 c.f.m.	6 single-arm. 4-pole 2. 1500v. 25 h.p. motor-blower sets each 3900 c.f.m.	6 single-arm. 6-pole 4. 1500v. 7·5 h.p. motor-blower sets each 5250 c.f.m.	4 single-armature 4. 1500v. motor-blower sets
750	750	750	1350
1920	1675	1770	3300
2415	2270	2340	3700
24·2	24·8	24·8	45
28,800	24,800	27,100	27,000
21·7	21·7	21·7	43
41,000	39,600	40,400	31,500
57,400	58,500	61,000	44,000
50	50	50	81
Nose-suspension	Nose-suspension	Nose-suspension	Buchli link
3·77	4·47	4·14	2·31
None	None	None	None
Air on loco and rolling stock	Air on loco and rolling stock	Air on loco and rolling stock	Air on loco and rolling stock
E.P. contactors*	E.P. contactors*	E.P. contactors*	E.P. contactors‡
6 3 2	6 3 2	6 3 2	4 2 –
– 2 3	– 2 3	– 2 3	– 2 4
3 3 3	3 3 3	3 3 3	6 6 5
9	9	9	17
73% and 58%	80% and 60%	83% and 62%	75 66·5 48 39 26%
—	—	—	Tapps. and shunts
None	None	None	High Speed
Regenerative	Regenerative	Regenerative	None
80v. 40kw. M.G. set	2. 70v. 15kw. genr. on blower sets	50v. 60kw. M.G. set	—
70v. from battery	70v. from battery	64v. from battery	72v. from battery
Charged in series with auxiliaries	Charged in series with auxiliaries	Charged in series with auxiliaries	72v.85AH.charged in series with aux.
2 two-cylinder	2 two-cylinder	2 two-cylinder	2
1500v.	1500v. 20 h.p.	1500v. 13 h.p.	1500v.
46	50	38	46
—	—	—	—
—	—	—	—
—	—	—	—
2 double	2 double	2 double	2 double
None	None	None	at 1500v.

† Société National des Chemins de Fers Français (State).
‡ With camshaft field reduction gear.

Country	France	France
Railway	S.N.C.F.*	S.N.C.F.*
Gauge	4′ 8½″	4′ 8½″
Nominal Supply Voltage	1500	1500
Railway Type or Serial Nos.	101 etc.	2D2 705 to 720
Makers of Mechanical Parts	Alsthom	Schneider-Batignolles
Makers of Electrical Parts	Alsthom	Jeumont-Oerlikon
Type of Service	Mixed	Express
Axle Classification	$B_0 + B_0$	$2 - D_0 - 2$
Year First in Service	1937	1938
Total Number in Service	35	16
Total Weight in Tons	79	128
Adhesive Weight in Tons	79	78·7
Weight of Mechanical Parts (tons)	45·7	—
Weight of Electrical Parts (tons)	31·3	—
Overall Length	42′ 3″	58′ 4″
Total Wheelbase	29′ 5″	47′ 3″
Rigid Wheelbase	9′ 8″	19′ 10½″
Driving Wheel Diameter	55¼″	69″
Carrying Wheel Diameter	—	38″
Traction Motors (No. and Type)	4 single-armature	4 twin-armature
Motor Ventilation Details	2. 1500v. motor-blower sets	forced
Armature Voltage	1350	750
Total Motor Rated Horse Power — Continuous	1660	3880
Total Motor Rated Horse Power — One Hour	1785	4590
Locomotive Continuous Rating — Speed in m.p.h.	39·5	52·8
Locomotive Continuous Rating — Tractive Effort(lbs.)	15,350	28,350
Locomotive One-Hour Rating — Speed in m.p.h.	38·3	46·9
Locomotive One-Hour Rating — Tractive Effort(lbs.)	17,200	36,200
Maximum Tractive Effort (lbs.)	35,000	35,300
Maximum Service Speed (m.p.h.)	59	81
System of Drive	Nose-suspension	Quill and link
Gear Ratio	3·27	3·333
Roller Bearings used on	None	—
Mechanical Brakes	Air on loco and rolling stock	Air on loco and rolling stock
Control System—Main Circuits	E.P. contactor†	E.P. contactor
Armature Combinations — Series	4 2 –	8 4 2
Armature Combinations — Parallel	– 2 4	– 2 4
Total Field Values	4 4 3	4 4 4
Economical Running Speeds	11	12
Values of Reduced Field	75, 50 and 40%	3
Obtained by	Tapps. and shunts	Shunts
Additional Circuit Breakers	High Speed	—
Electric Braking	None	None
Excitation by	—	—
Low Tension Supply	72v. from battery	72v. from battery
Battery	72v.85AH.charged in series with aux.	72v.72AH.charged in series with aux.
Compressors — Number and Type	2	2
Compressors — Motor Volts and Rating	1500	1350
Compressors — Capacity cu. ft./min.	56	48
Exhausters — Number and Type	—	—
Exhausters — Motor Volts and Rating	—	—
Exhausters — Capacity cu. ft./min.	—	—
Pantographs—Number and Type	2 double	2 double
Train Heating System	at 1500v.	at 1500v.

* Société National des Chemins de Fers Français (State).
† With camshaft field reduction gear.

FRANCE S.N.C.F.* 4′ 8½″ 1500 2D2 5546 to 5550 Cie F.L. Cie E.M.	FRANCE S.N.C.F.* 4′ 8½″ 1500 2D2 5302 to 5306 Alsthom Alsthom	FRANCE S.N.C.F.* 4′ 8½″ 1500 BB 241 to 264 Alsthom Alsthom	FRANCE St. Georges-La-Mure-Gap 3′ 3⅜″ 2400v. (2 × 1200) T6 to T10 A.N.F.Blanc-Misseron Sécheron
Express $2-D_0-2$ 1942 5	Express $2-D_0-2$ 1942-5 5	Mixed B_0-B_0 1938 24	Mixed B_0+B_0 1933 5
131 78·7 — —	130 78·7 — —	78·6 78·6 — —	59 59 33 26
58′ 4″ 47′ 3″ 19′ 10½″ 69″ 38″	58′ 4″ 47′ 3″ 19′ 10½″ 69″ 38″	42′ 6″ 29′ 4″ 9′ 2½″ 53″ —	39′ 4″ 25′ 6¾″ 7′ 2½″ 41⅝ —
4 single-armature 4. 1500v. motor-blower sets each 4240 c.f.m. 1500 3520 3700	2 triple-armature 6. 750v. motor-blower sets each 3530 c.f.m. 750 3850 4290	4 single-armature 2. 750v. motor-blower sets each 6350 c.f.m. 1500 1680 1830	4 twin-armature 1 motor-blower set 17,600 c.f.m. 1200 740 920
43·6 29,900 42·9 31,900 35,300 93	47·9 29,750 46·6 34,050 35,300 93	29·9 21,600 28·0 24,050 35,300 65	17·2 16,000 18·4 22,000 34,000 25
Buchli 2·311 carrying axles Air on loco and rolling stock	Quill and link 3·148 carrying axles Air on loco and rolling stock	Nose-suspension 2·917 None Air on loco and rolling stock	Quill & Séch. spring 5·4 motors only Vacuum-locos and stock
Camshaft 4 2 — — 2 4 5 5 5 15 4 shunts	E.P. contactor 6 3 2 — 2 3 4 4 4 12 3 shunts	E.P. contactor 4 2 — — 2 4 3 3 2 8 2 shunts	Mechano pneumatic‡ 2 4 1 1 None —
— None — 72v. from battery 72v. 72AH. Nickel-Cadmium§	— None — 72v. from battery 72v. 72AH. Nickel-Cadmium§	— None — 72v. from battery 72v. 72AH. Nickel-Cadmium§	E.P. contactors Rheostatic Self 2. 36v. 85 kw. genr on blower set 36v. 55AH.
2 1350 48 — — —	2 1350 64 — — —	1 1350 64 — — —	2 rotary 1200 7 2 rotary 1200 106
2 double at 1500v.	2 double at 1500v.	2 double at 1500v.	4 single at 2400v.

‡ With E.P. drum reversers.
§ Charged in series with auxilliaries.

Country	Great Britain	India
Railway	L.N.E.R.	Gt. Indian Peninsular
Gauge	4′ 8½″	5′ 6″
Nominal Supply Voltage	1500	1500
Railway Type or Serial Nos.	6701 etc.	4001
Makers of Mechanical Parts	L.N.E.R.	H.L.
Makers of Electrical Parts	M.V.	G.E.C.-Oerlikon
Type of Service	Mixed	Express
Axle Classification	$B_0 + B_0$	$2 - C_0 - 2$
Year First in Service	1941	1928
Total Number in Service	1 (70 on order)	1
Total Weight in Tons	88	114
Adhesive Weight in Tons	88	60
Weight of Mechanical Parts (tons)	—	69·5
Weight of Electrical Parts (tons)	—	44·5
Overall Length	50′ 4″	56′ 2″
Total Wheelbase	35′ 0″	43′ 4″
Rigid Wheelbase	—	15′ 0″
Driving Wheel Diameter	50″	74″
Carrying Wheel Diameter	—	36″
Traction Motors (No. and Type)	4 single-armature	3 twin-armature
Motor Ventilation Details	2 motor-blower sets each 4000 c.f.m.	1. 1500v. motor with two blowers
Armature Voltage	750	750
Total Motor Rated Horse Power — Continuous	1360	2130
Total Motor Rated Horse Power — One Hour	1868	2250
Locomotive Continuous Rating — Speed in m.p.h.	56	37
Locomotive Continuous Rating — Tractive Effort(lbs.)	8,800	21,600
Locomotive One-Hour Rating — Speed in m.p.h.	45	36
Locomotive One-Hour Rating — Tractive Effort(lbs.)	15,400	23,700
Maximum Tractive Effort (lbs.)	45,000	32,000
Maximum Service Speed (m.p.h.)	65	75
System of Drive	Nose-suspension	Quill & spring link
Gear Ratio	4·12	3·74
Roller Bearings used on	motors only	None
Mechanical Brakes	Air on loco—Vacuum on stock	Air on loco—Vacuum on stock
Control System—Main Circuits	E. P. contactor*	E.P. contactor
Armature Combinations — Series	4 2	6 3 2
Armature Combinations — Parallel	– 2	– 2 3
Total Field Values	5 5	3 3 3
Economical Running Speeds	10	9
Values of Reduced Field	4	82% and 60%
Obtained by	shunts	shunts
Additional Circuit Breakers	None	None
Electric Braking	Regenerative	None
Excitation by	25kw. genr. on blower set	—
Low Tension Supply	50v. 5kw. genr. on blower set	50v. from 2kw. M.G. set
Battery	50v.	50v. 90AH.
Compressors — Number and Type	1 reciprocating	2 reciprocating
Compressors — Motor Volts and Rating	1500v.	1500v.
Compressors — Capacity cu. ft./min.	38	38
Exhausters — Number and Type	1 rotary	2 rotary
Exhausters — Motor Volts and Rating	1500	1500
Exhausters — Capacity cu. ft./min.	200	242
Pantographs—Number and Type	2 single	2 double
Train Heating System	Elec.-heated boiler	None

* And drum reversers.

INDIA Gt. Indian Peninsular 5′ 6″ 1500 4002 H.L. Brown-Boveri	INDIA Gt. Indian Peninsular 5′ 6″ 1500 4003 etc. S.L.M. M.V.	INDIA Gt. Indian Peninsular 5′ 6″ 1500 4500 etc. S.L.M.—Vulcan M.V.	ITALY Circumvesuvian 3′ 1½″ 1200 — Tech. Br.-Boveri Tech. Br.-Boveri
Express $2 - C_0 - 2$ 1928 1	Express $1 - C_0 - 2$[1] 1928 23	Freight C – C 1928 41	Mixed $1 - D_0 - 1$ 1930 1
111 59·6 66 45	104·6 63 66·6 38·0	123 123 74·2 48·7	57·3 41·0 41·0 16·3
56′ 2″ 46′ 0″ 15′ 0″ 69″ 36″	53′ 6″ 39′ 0″ 15′ 0″ 63″ 43″	66′ 1″ 54′ 11″ 15′ 1″ 48″ —	41′ 1″ 29′ 3″ — 55″ 31½″
6 single-armature 2. 1500v. motor-blower sets 750 1848 2388	6 single-armature 2. 1500v. motor-blower sets 750 1900 2160	4 single-armature 2. 1500v. motors and 4 blowers 1500 2600 2800	8 single-armature Forced 600 — 1000
38·9 17,000 35·4 24,450 33,000 70	39·0 17,500 37·0 21,500 35,000 70	20·0 48,000 18·0 60,000 75,000 45	— — 26·1 13,700 20,950 43·5
Buchli link 3·24 None Air on loco and Vacuum on stock	Winterthur Universal 3·66 None Air on loco and Vacuum on stock	Jackshaft & coup rod. 4·15 None Air on loco and Vacuum on stock	Buchli link 7·43 None Air on loco and rolling stock
E.P. camshaft 6 3 2 – 2 3 3 3 3 9 2 (min. 65%) Tapps. and shunts	E.P. contactor 6 3 2 – 2 3 3 3 3 9 2 (min. 56%) Tappings	E.P. contactor 4 2 – – 2 4 3 3 3 9 2 (min. 60·5%) Shunts	Mech.-camshaft 2 4 3 3 2 Tapps. and shunts
None None — 50v. 1·8kw. M.G. set 50v. 100AH.	None None — 50v. from genr. on blower set 50v. 90AH.	None Regenerative 2. 11·5kw. axle-driven exciters 50v. from genr. on blower set 50v. 90AH.	Fitted None — — —
1 reciprocating 1500 26 2 rotary 1500 234	2 reciprocating 1500 38 2 rotary 1500 242	2 reciprocating 1500 38 2 rotary 1500 242	1 1200 — — — —
2 double None	2 double None	2 double None	2 single None

Country	ITALY	ITALY
Railway	DOLOMITES	STATE
Gauge	3′ 1½″	4′ 8½″
Nominal Supply Voltage	2700	3000
Railway Type or Serial Nos.	—	E326
Makers of Mechanical Parts	S.A. Officine	Breda
Makers of Electrical Parts	Tech. Br.-Bov.	Breda
Type of Service	Freight	Express
Axle Classification	$B_0 - B_0$	$2 - C_0 - 2$
Year First in Service	1931	1930
Total Number in Service	2	12
Total Weight in Tons	35	112
Adhesive Weight in Tons	35	60
Weight of Mechanical Parts (tons)	—	63
Weight of Electrical Parts (tons)	—	49
Overall Length	40′ 4″	53′ 6″
Total Wheelbase	28′ 0″	43′ 4″
Rigid Wheelbase	7′ 8″	16′ 5″
Driving Wheel Diameter	40½″	74″
Carrying Wheel Diameter	—	43¾″
Traction Motors (No. and Type)	4 single-armature	3 twin-armature 4-pole
Motor Ventilation Details	Self	1. 3000v. 53·5 h.p. blower set
Armature Voltage	1350	1500
Total Motor Rated Horse Power — Continuous	400	2535
Total Motor Rated Horse Power — One Hour	520	2810
Locomotive Continuous Rating — Speed in m.p.h.	19·2	— —
Locomotive Continuous Rating — Tractive Effort (lbs.)	7,280	— —
Locomotive One-Hour Rating — Speed in m.p.h.	17·4	56 49·5
Locomotive One-Hour Rating — Tractive Effort (lbs.)	10,590	18,700 21,200
Maximum Tractive Effort (lbs.)	19,600	33,600
Maximum Service Speed (m.p.h.)	28·0	93 72
System of Drive	Nose-suspension	Bianchi quill & spring
Gear Ratio	5·11	2·88 3·71
Roller Bearings used on	None	motors only
Mechanical Brakes	Air on loco and rolling stock	Air on loco and rolling stock
Control System—Main Circuits	Mech. camshaft	E.P. contactor
Armature Combinations — Series	4 2	6 3 2
Armature Combinations — Parallel	1 2	– 2 3
Total Field Values	1 1	2 2 2
Economical Running Speeds	2	6
Values of Reduced Field	None	1
Obtained by	—	Shunts
Additional Circuit Breakers	E.P. contactors	None
Electric Braking	Rheostatic	None
Excitation by	Self	—
Low Tension Supply	—	90v. 30kw. genr. on blower set or 24v. from battery
Battery	155AH.	90v. (24v. tap)
Compressors — Number and Type	1	2 two-cylinder
Compressors — Motor Volts and Rating	2700v. 6 h.p.	90v. 13·5 h.p.
Compressors — Capacity cu. ft./min.	19·8	35
Exhausters — Number and Type	—	—
Exhausters — Motor Volts and Rating	—	—
Exhausters — Capacity cu. ft./min.	—	—
Pantographs—Number and Type	2 single	2 single
Train Heating System	Electric	None

ITALY STATE 4′ 8½″ 3000 E428 Ansaldo, Breda, Marelli Fiat. Tech Br.-Bov. etc.	ITALY STATE 4′ 8½″ 3000 E626 Ansaldo, Breda, Marelli Fiat. Tech Br.-Bov. etc.	ITALY STATE 4′ 8½″ 3000 E636 Breda, Marelli and others	ITALY STATE 4′ 8½″ 3000 E424 Breda, Tech Br.-Bov. Ansaldo, Marelli etc.
Express $2 - B_0 + B_0 - 2$ 1934 242	Mixed $B_0 + B_0 + B_0$ 1927 448	Mixed $B_0 + B_0 + B_0$ 1939 108	Mixed $B_0 + B_0$ 1946 76
128 73·8 82·5 45·5	94·5 94·5 45·0 49·3	99·5 99·5 — —	71 71 — —
62′ 4″ 52′ 1½″ 7′ 8½″ 74″ 43¾″	49′ 0″ 37′ 11″ 8′ 0½″ 49″ —	59′ 11″ 44′ 6″ — 49″ —	37′ 10″ 26′ 3″ — 49″ —
4 twin-arm. 4-pole 2. 3000v. 13·5 h.p. motor-blower sets each 4000 c.f.m. 1500 3380 3750	6 single-arm. 4-pole 2. 3000v. 13·5 h.p. motor-blower sets each 4000 c.f.m. 1500 2535 2810	6 single-arm. 4-pole 2. 3000v. 13·5 h.p. motor-blower sets each 4000 c.f.m. 1500 2525 2800	4 single-armature Self *or* 2. 3000v. motor-blower sets each 4000 c.f.m. 1500 — 2150
— — — — 56 49·5 25,200 28,200 41,100 93 72	45·4 36·0 20,200 26,400 42·8 24·8 24,000 41,500 46,500 72 56	35·4 24,250 34·1 28,700 49,600 81	35·4 18,550 34·1 21,850 35,300 81
Bianchi quill & spring 2·88 3·71 motors only Air on loco and rolling stock	Nose-suspension 2·34 3·04 motors only Air on loco and rolling stock	Nose-suspension 2·32 3·1 motors only Air on loco and rolling stock	Nose-suspension 3·1 — Air on loco and stock
E.P. contactor 8 4 2 – 2 4 2 2 2 6 1 Shunts	E.P. contactor 6 3 2 – 2 3 2 2 2 6 1 Shunts	E.P. contactor 6 3 2 – 2 3 2 2 2 6 1 Tappings	E.P. contactor 4 2 – 2 2 2 4 1 Tap and shunt
None None — 90v. from two 4kw. genr. on blower sets (24v. from battery) 90v. (24v. tap) 125AH	None None — 90v. from two 4kw. genr. on blower sets (24v. from battery) 90v. (24v. tap)	None None — 90v. 90v. 125AH.	None None — 90v. —
2 two-cylinder 3000v. 13·5 h.p. 35 — — —	2 two-cylinder 3000v. 13·5 h.p. 35 — — —	2 3000 35 — — —	2 3000v. 13·5 h.p. 35 — — —
2 single None	2 single None	2 single None	2 single None

Country	JAPAN	JAPAN
Railway	Government	Government
Gauge	3′ 6″	3′ 6″
Nominal Supply Voltage	1500	600v. o/h line + 3rd rail
Railway Type or Serial Nos.	7000–1	10040–1
Makers of Mechanical Parts	Brown-Boveri	Brown-Boveri
Makers of Electrical Parts	Brown-Boveri	Brown-Boveri
Type of Service	Passenger	Mixed
Axle Classification	$1-D_0-1^{(1)}$	B – B (Rack & Adh)
Year First in Service	1926	1926
Total Number in Service	2	2
Total Weight in Tons	77·5	59·5
Adhesive Weight in Tons	59	59·5
Weight of Mechanical Parts (tons)	48	40·0
Weight of Electrical Parts (tons)	29·5	19·5
Overall Length	44′ 8″	42′ 8″
Total Wheelbase	33′ 1½″	29′ 6″
Rigid Wheelbase	17′ 4½″	8′ 2½″
Driving Wheel Diameter	63″	42″
Carrying Wheel Diameter	37″	—
Traction Motors (No. and Type)	4 single-arm 6-pole	3 single-arm. 6-pole
Motor Ventilation Details	2650 c.f.m. per motor	2970 c.f.m. per motor (3 motor-blower sets)
Armature Voltage	750	600
Total Motor Rated Horse Power — Continuous	2000	—
Total Motor Rated Horse Power — One Hour	2340	830
		Adh / Rack
Locomotive Continuous Rating — Speed in m.p.h.	44·7	— / —
Locomotive Continuous Rating — Tractive Effort (lbs.)	15,650	— / —
Locomotive One-Hour Rating — Speed in m.p.h.	41·0	11·2 / 9·65
Locomotive One-Hour Rating — Tractive Effort (lbs.)	19,850	11,000 / 26,500
Maximum Tractive Effort (lbs.)	33,100	33,100
Maximum Service Speed (m.p.h.)	62	15·5
System of Drive	Buchli link	Inv. scot yoke Abt. rack
Gear Ratio	3·34	4·95 3·7
Roller Bearings used on	None	None
Mechanical Brakes	Air on loco—Vacuum on stock	Air on loco—Vacuum on stock
Control System—Main Circuits	Motor camshaft	Motor camshaft
Armature Combinations — Series	4 2	2 1 — 2 adhesion in parallel in series with rack motor
Armature Combinations — Parallel	– 2	– 2
Total Field Values	1 2	2 2
Economical Running Speeds	3	4 or All 3 motors in parallel
Values of Reduced Field	1	1
Obtained by	Tapping	—
Additional Circuit Breakers	E.P. contactor	E.P. contactor
Electric Braking	None	Rheostatic
Excitation by	—	Self
Low Tension Supply	113v. 5·8kw. generator	100v. 2kw. M.G. set
Battery	100v. 100AH.	100v. 40AH.
Compressors — Number and Type	1	1
Compressors — Motor Volts and Rating	—	600v.
Compressors — Capacity cu. ft./min.	—	—
Exhausters — Number and Type	1	1
Exhausters — Motor Volts and Rating	—	600v.
Exhausters — Capacity cu. ft./min.	—	—
Pantographs—Number and Type	2 single	1 single
Train Heating System	None	None

Morocco Moroccan 4′ 8½″ 3000 E501, E601 etc. C.E.F. C.E.F.	Netherlands East Indies State 3′ 6″ 1500 3001 etc. S.L.M. Brown-Boveri	New Zealand Government 3′ 6″ 1500 101 etc. H.L. E.E.Co.	Poland State 4′ 8½″ 3000 101 etc. M.V.—Fablok M.V.
Mixed $B_0 + B_0$ 1927 1928 10 23[2]	Passenger $1 - D_0 - 1$[1] 1925 4	Mixed $1 - D_0 - 2$ 1938 8 2	Mixed $B_0 + B_0$ 1936 6
72 80 72 80 — 43 — 37	68 50·5 42·5 25·5	88 64 61·5 26·5	74 74 42·7 30·5
42′ 2½″ 29′ 5″ 9′ 8½″ 55½″ —	41′ 2″ 29′ 5″ 6′ 6½″ 59″ 30½″	46′ 2″ 34′ 6″ 13′ 6″ 45″ 30½″	44′ 6″ 30′ 6″ 9′ 3″ 48″ —
4 single-armature Forced 1350 985 1205 1300 1430	4 single-arm. 6-pole 2. 1500v. 16 h.p. motors with 4 blowers each 3500 c.f.m. 675 1180 1475	4 single-arm. 4-pole 2. 1500v. 6 h.p. motors with 4 blowers each 3200 c.f.m. 750 900 1240	4 single-armature 2. 3000v. motor- blower sets 1500 1800 2200
47·5 29·1 7,700 16,000 41·2 27·0 11,550 19,800 36,000 53,000 37 47	37·8 11,000 34·5 15,200 28,700 56	29·3 11,600 25·5 18,000 44,000 55	42·2 15,440 40·3 19,850 — 62
Nose-suspension 4·05 3·95 None Air on loco and stock	Buchli link 2·79 None Vacuum—loco and stock	Quill and cup 3·73 motors and all axles Air on loco and stock	Nose-suspension 3·13 None Air on loco and stock
E.M. Camshaft 4 2 – 2 3 3 6 70, 56% 75, 50% Shunts	E.P. Camshaft 4 2 – 2 1 2 3 1 Tappings	E.P. contactor 4 2 – 2 3 3 6 2 Tappings	E.P. contactor 4 2 – 2 3 3 6 2 (min. 61½%) —
High Speed Regenerative M.G. set 120v. from M.G. set 120v. 64AH.	E.P. quick-acting Rheostatic 3kw. M.G. set 65v. 2·5kw. M.G. set 65v. 122AH.	High Speed current limiter None Rheostatic — Self 120v. 4kw. M.G. set 120v. 52AH.	None None — 2. 110v. 10kw. genr. on blow. set 110v.
2 120 64 — — —	1 reciprocating 1500 20 1 rotary — 144	2 reciprocating 1500v. 8 h.p. 38 — — —	2 two-cylinder 110 70 — — —
2 double None	2 single None	2 double Oil fired boil. None	2 single None

Country	South Africa	South Africa
Railway	S.A. Rlys. & Harbs.	S.A. Rlys. & Harbs.
Gauge	3′ 6″	3′ 6″
Nominal Supply Voltage	3000	3000
Railway Type or Serial Nos.	1 etc.	98 etc.
Makers of Mechanical Parts	M.V., S.L.M., R.S.	M.V., S.L.M., H.L. Werkspoor
Makers of Electrical Parts	M.V.	M.V.
Type of Service	Mixed	Mixed
Axle Classification	$B_0 + B_0$	$B_0 + B_0$
Year First in Service	1925	1936 1937
Total Number in Service	78 17	75 2
Total Weight in Tons	66·5 69·0	66
Adhesive Weight in Tons	66·5 69·0	66
Weight of Mechanical Parts (tons)	39 40·2	37·5
Weight of Electrical Parts (tons)	27·5 28·7	28·2
Overall Length	43′ 8″	43′ 8″
Total Wheelbase	30′ 11″	30′ 11″
Rigid Wheelbase	9′ 3″	9′ 3″
Driving Wheel Diameter	48″	48″
Carrying Wheel Diameter	—	—
Traction Motors (No. and Type)	4 single-armature	4 single-armature
Motor Ventilation Details	2. 3000v. motor-blower sets each 3500 c.f.m.	2. 3000v. motor-blower sets each 3500 c.f.m.
Armature Voltage	1500	1500
Total Motor Rated Horse Power — Continuous	1000	1020
Total Motor Rated Horse Power — One Hour	1200	1200
Locomotive Continuous Rating — Speed in m.p.h.	23	23 27·8
Locomotive Continuous Rating — Tractive Effort (lbs.)	16,400	16,800 13,900
Locomotive One-Hour Rating — Speed in m.p.h.	21·5	21·5 26
Locomotive One-Hour Rating — Tractive Effort (lbs.)	21,200	21,200 17,500
Maximum Tractive Effort (lbs.)	39,000	37,000
Maximum Service Speed (m.p.h.)	45	45 55
System of Drive	Nose-suspension	Nose-suspension
Gear Ratio	4·41	4·41 3·65
Roller Bearings used on	None	Motors and axles
Mechanical Brakes	Air on loco—Vacuum on stock	
Control System—Main Circuits	*	†
Armature Combinations — Series	4 2	4 2 4 2
Armature Combinations — Parallel	– 2	– 2 – 2
Total Field Values	2 2	2 2 Fine graduation by induc. shunts and telemotor
Economical Running Speeds	4	4
Values of Reduced Field	1	1
Obtained by	Tappings	Tapps.
Additional Circuit Breakers	None	None
Electric Braking	Regenerative	Regenerative
Excitation by	80v. 28kw. genr. on one blower set	80v. 28kw. genr. on one blower set
Low Tension Supply	105v. 16kw. genr. on one blower set	105v. 16kw. genr. on one blower set
Battery	100v.	100v. 105v.
Compressors — Number and Type	1 reciprocating	1 reciprocating
Compressors — Motor Volts and Rating	100	105
Compressors — Capacity cu. ft./min.	38	38
Exhausters — Number and Type	1 rotary	1 rotary
Exhausters — Motor Volts and Rating	100	105
Exhausters — Capacity cu. ft./min.	163	163
Pantographs—Number and Type	2 double	2 single
Train Heating System	None	None

* E.P. contactors and E.P. cam groups. † E.P. contactors and drum switches.

SPAIN Northern 5′ 6″ 1500 7201 etc. B.W. Brown-Bov.-Oerlikon	SPAIN Northern 5′ 6″ 1500 7301 S.N.C. M.V.	SPAIN Northern 5′ 6″ 1500 7001 etc. — Oerlikon	SPAIN Northern 5′ 6″ 1500 7101 etc. — Oerlikon
Express $2-C_0+C_0-2$ 1929 1935 12 18	Express $2-C_0+C_0-2$ 1931 1	Mixed C_0+C_0 1928 10	Mixed $1-C_0+C_0-1$ 1928 27
143 94·5 98·5 44·5	149 97·2 100 49	102 102 67 35	111·2 90 76·2 35
78′ 9″ 67′ 3″ 14′ 9″ 61½″ 34″	82′ 0½″ 67′ 3″ 14′ 9″ 61½″ 34″	52′ 1″ 39′ 5″ 14′ 7″ 51″ —	68′ 10″ 53′ 9″ 14′ 7″ 51″ —
6 single-armature Forced 750 2760 3420 3240 4200	12 single-armature Forced 500 3000 3600	6 single-armature 1. 1500v. 80 h.p. motor with two blowers 450 1650 2040	6 single-armature 1. 1500v. 80 h.p. motor and two blowers 450 1650 2040
37·0 40·1 26,200 29,950 34·8 37·9 34,450 40,850 53,000 56	— — 34·2 40,000 57,600 56	22·2 27,100 20·6 35,900 53,000 56	22·2 27,100 20·6 35,900 53,000 56
‡ 3·43 None	Winterthur Universal 4·484 motors	Nose-suspension 4·94 None	Nose-suspension 4·94 None
Vacuum on locomotives and rolling stock			
E.P. camshaft 6 3 2 — 2 3 3 3 3 9 2 Tapps and shunts	E.P. contactor 12 6 3 — 2 4 3 3 3 9 2 Tappings	E.P. contactor 6 3 — 2 3 3 6 75% and 50% Shunts	E.P. contactor 6 3 — 2 3 3 6 75% and 50% Shunts
E.P. quick-acting Regenerative M.G. set 65v. from braking M.G. set or battery 65v. 430AH.	None Regenerative M.G. set 100v. from M.G. set 100v.	High Speed Regenerative 30kw. genr. on blower set 65v. from braking M.G. set or battery 65v. 575AH.	High Speed Regenerative 30kw. genr. on blower set — 65v. 575AH.
1 65 35 2 1500 and 65 230 and 144	1 rotary — — 2 rotary — —	1. 65v. 13·5 h.p. motor driving one reciprocating compressor and one recip. exhauster 1. 1500v. 20 h.p. motor driving two reciprocating compressors	1. 65v. 13·5 h.p. motor driving one reciprocating compressor and one recip. exhauster 1. 1500v. 20 h.p. motor driving two reciprocating compressors
2 double None	2 double None	2 double at 1500v.	2 double at 1500v.

‡ Twin Buchli between wheels.

Country	SPAIN	SPAIN
Railway	Bilbao-Portugalette	STATE
Gauge	5′ 6″	5′ 6″
Nominal Supply Voltage	1650	1500
Railway Type or Serial Nos.	22 etc.	7401 etc.
Makers of Mechanical Parts	B.W.	Con. Devis
Makers of Electrical Parts	G.E.	Sécheron
Type of Service	Freight	Mixed
Axle Classification	$B_0 + B_0$	$C_0 + C_0$
Year First in Service	1932	1945
Total Number in Service	5	24
Total Weight in Tons	67	99
Adhesive Weight in Tons	67	99
Weight of Mechanical Parts (tons)	42·7	64
Weight of Electrical Parts (tons)	23·5	35
Overall Length	41′ 4″	56′ 7¼″
Total Wheelbase	27′ 10″	41′ 2½″
Rigid Wheelbase	8′ 2″	14′ 9½″
Driving Wheel Diameter	50″	51¼″
Carrying Wheel Diameter	—	—
Traction Motors (No. and Type)	4 single-armature	6 single-armature
Motor Ventilation Details	2. 825v. 5 h.p. motor-blower sets each 3800 c.f.m.	1 motor-blower set 21,000 c.f.m.
Armature Voltage	825	450
Total Motor Rated Horse Power: Continuous	1135	2400
Total Motor Rated Horse Power: One Hour	1230	3000
Locomotive Continuous Rating: Speed in m.p.h.	15·5	32·5
Locomotive Continuous Rating: Tractive Effort (lbs.)	26,500	27,500
Locomotive One-Hour Rating: Speed in m.p.h.	14·1	29·5
Locomotive One-Hour Rating: Tractive Effort (lbs.)	29,650	37,500
Maximum Tractive Effort (lbs.)	37,500	53,000
Maximum Service Speed (m.p.h.)	43	56
System of Drive	Nose-suspension	Nose-suspension
Gear Ratio	4·63	4·94
Roller Bearings used on	motors only	motors only
Mechanical Brakes	Vacuum on loco and rolling stock	Vacuum on loco and rolling stock
Control System—Main Circuits	E.P. contactor	E.P. contactor
Armature Combinations: Series	4 2	6 3
Armature Combinations: Parallel	– 2	– 2
Total Field Values	1 2	3 3
Economical Running Speeds	3	6
Values of Reduced Field	75%	2
Obtained by	Shunts	Shunts
Additional Circuit Breakers	—	—
Electric Braking	None	Regenerative
Excitation by	—	85v. 61kw. genr. on blower set
Low Tension Supply	65v. 10kw. M.G. set	85v. 61kw. genr. on blower set
Battery	65v.	60v. 187AH.
Compressors: Number and Type	1	1 rotary
Compressors: Motor Volts and Rating	65	1500
Compressors: Capacity cu. ft./min.	25	18·5
Exhausters: Number and Type	1	2 rotary
Exhausters: Motor Volts and Rating	65	1500
Exhausters: Capacity cu. ft./min.	80	—
Pantographs—Number and Type	2 double	2 single
Train Heating System	None	None

SPAIN	SWITZERLAND	U.S.A.	U.S.A.
Vascongados	Montreux-Bernese	Baltimore and	Cleveland
	Oberland	Ohio	Union Terml.
3′ 3⅜″	3′ 3⅜″	4′ 8½″	4′ 8½″
1500	700	600	3000
—	—	17–18	1050 etc
—	S.I.G.N.	A.L.C.O.	A.L.C.O.
Brown-Boveri	Brown-Boveri	G.E.	G.E.
Mixed	Passenger	Mixed	Express
$B_0 - B_0$	$B_0 - B_0 - B_0$	$B_0 + B_0$	$2 - C_0 + C_0 - 2$
1928	1931	1927	1930
10	2	2	22
46	63	107	187
46	63	107	139
—	38	81·2	118
—	25	25·8	64·5
36′ 10″	55′ 10″	41′ 4″	80′ 0″
24′ 10½″	43′ 8″	28′ 3″	69′ 0″
7′ 9″	7′ 6¾″	9′ 6″	15′ 0″
39⅜″	37¼″	50″	48″
—	—	—	36″
4 single-armature	6 single-armature	4 single-armature	6 single-armature 4-pole
Forced	Self	—	2. 1500v. two speed motor-blower sets
750	650	600	1500
756	750	660	2635
1020	1000	1100	3030
33·1	15·1	14·5	—
8,370	17,650	19,400	—
29·5	13·5	12·7	37·0
11,500	26,000	32,000	30,600
25,750	39,700	59,900	78,000
41·5	37·3	35	70
Nose-suspension	Nose-suspension	Nose-suspension	Nose-suspension
—	4·94	4·37	2·74
—	motors only	—	None
Vacuum on loco	Vacuum on loco	Air on loco and	Air on loco and
and rolling stock	and rolling stock	stock	and rolling stock
Mech. camshaft	E.P. camshaft	E.P. contactor	E.P. camshaft
4 2	2 –	2 –	6 3 2
– 2	3 6	2 4	– 2 3
2 3	4 4	—	3 3 3
5	8	—	9
2	2 1	—	2
Tapps. and shunt	tappings over-excited	—	Shunts
None	E.P. contactors	None	High Speed
None	Regenerative	None	None
—	from contact wire	—	—
—	—	—	1500v. from dynamotor 32v. from coup. genr.
—	36v. 40AH.	—	32v.
1	2	—	2 two-stage
1500	650	—	1500
—	—	—	150
1	2	—	—
1500	650	—	—
—	—	—	—
2 double	2 double	None	2 double
None	at 700v.	None	Oil-fired boiler

Country	U.S.A.	U.S.A.
Railway	Illinois Central	Michigan Central
Gauge	4′ 8½″	4′ 8½″
Nominal Supply Voltage	1500	600
Railway Type or Serial Nos.	10,000 etc.	170–171
Makers of Mechanical Parts	Baldwin	A.L.C.O.
Makers of Electrical Parts	Westinghouse	G.E.
Type of Service	Freight & shunting	Mixed
Axle Classification	$B_0 + B_0$	$B_0 + B_0$
Year First in Service	1929	1926
Total Number in Service	4	2
Total Weight in Tons	89	112
Adhesive Weight in Tons	89	112
Weight of Mechanical Parts (tons)	56·5	84·3
Weight of Electrical Parts (tons)	32·5	27·7
Overall Length	40′ 1″	42′ 8″
Total Wheelbase	27′ 3″	28′ 10″
Rigid Wheelbase	8′ 10″	9′ 6″
Driving Wheel Diameter	45″	48″
Carrying Wheel Diameter	—	—
Traction Motors (No. and Type)	4 single-armature	4 single-armature
Motor Ventilation Details	Forced	—
Armature Voltage	750	600
Total Motor Rated Horse Power: Continuous	1340	630
Total Motor Rated Horse Power: One Hour	1550	1250
Locomotive Continuous Rating: Speed in m.p.h.	18·9	14·9
Locomotive Continuous Rating: Tractive Effort(lbs.)	24,000	15,850
Locomotive One-Hour Rating: Speed in m.p.h.	17·7	12
Locomotive One-Hour Rating: Tractive Effort(lbs.)	31,000	39,100
Maximum Tractive Effort (lbs.)	49,800	62,700
Maximum Service Speed (m.p.h.)	40	40
System of Drive	Nose-suspension	Nose-suspension
Gear Ratio	4·19	4·37
Roller Bearings used on	None	None
Mechanical Brakes	Air on locomotives and rolling stock	
Control System—Main Circuits	E.P. contactor	E.P. contactor
Armature Combinations: Series	4 2	2 –
Armature Combinations: Parallel	– 2	2 4
Total Field Values	—	—
Economical Running Speeds	—	—
Values of Reduced Field	—	—
Obtained by	—	—
Additional Circuit Breakers	None	None
Electric Braking	None	None
Excitation by	—	—
Low Tension Supply	—	—
Battery	—	—
Compressors: Number and Type	—	—
Compressors: Motor Volts and Rating	—	—
Compressors: Capacity cu. ft./min.	—	—
Exhausters: Number and Type	—	—
Exhausters: Motor Volts and Rating	—	—
Exhausters: Capacity cu. ft./min.	—	—
Pantographs—Number and Type	1 double	None
Train Heating System	None	None

U.S.A.	U.S.A.	U.S.A.	U.S.A.
New York Central	New York Central	New York Central	Piedmont & Northern
4′ 8½″	4′ 8½″	4′ 8½″	4′ 8½″
600v. third rail and rigid overhead conductor			1500
1173 etc.	1200–1	1202 etc.	5611
A.L.C.O.	A.L.C.O.	A.L.C.O.	G.E.
G.E.	G.E.	G.E.	G.E.
Express	Freight	Freight	Freight
$B_0 - B_0 + B_0 - B_0$	$B_0 - B_0 + B_0 - B_0$	$C_0 + C_0$	$B_0 - B_0 + B_0 - B_0$
1926	1926	1930	1941
10	2	42	1
124	156·5	119	105¼
124	156·5	119	105¼
74·5	88·0	71	—
49·5	68·5	48	—
56′ 10″	68′ 2″	54′ 0″	63′ 4″
46′ 5″	55′ 3″	40′ 0″	52′ 6″
5′ 0″ and 6′ 6″	8′ 3″	14′ 6″	8′ 0″
36″	44″	44″	36″
—	—	—	—
8 single-arm. 2-pole	8 single-armature	6 single-armature	8 single-armature
1. 600v. motor-	2. 600v. motor-	2. 600v. motor-	2. 750v. motor-
blower set	blower sets	blower sets	blower sets
			each 4800 c.f.m.
600	600	600	750
1908	2680	2010	1885
2488	3320	2490	2400
56·1	24·2	24·2	20·5
12,750	41,200	30,900	34,500
50·6	22·3	22·3	18·4
18,440	55,800	41,800	49,000
69,450	57,850	66,625	59,000
75	60	60	—
Armatures	Nose-suspension	Nose-suspension	Nose-suspension
mounted on axles			
"Gearless"	3·45	3·45	3·77
None	None	None	motors only
Air on locomotives and on rolling stock			
E.M. contactor	E.P. camshaft	E.P. camshaft	E.P. contactor
4 2 –	4 2 –	2 –	4 2
2 4 8	2 4 8	3 6	2 4
1 1 1	3 3 3	3 3	2 2
3	9	6	4
None	2	2	1
—	Shunts	—	Shunts
High Speed	High Speed	High Speed	None
None	None	None	None
—	—	—	—
32v. from battery	32v. from battery	32v. from battery	32v.
32v. charged	32v. charged	32v. charged	32v. Lead-acid
from line	from line	from line	
1 reciprocating	2 reciprocating	2 reciprocating	2
600	600	600	1500
120	150	120	75
—	—	—	—
—	—	—	—
—	—	—	—
Overhead Shoes	Overhead Shoes	Overhead Shoes	2 double
Oil-fired boiler	None	None	None

Country	U.S.S.R.	Venezuela
Railway	Suram.	La Guaira & Caracas
Gauge	5′ 0″	3′ 0″
Nominal Supply Voltage	3000	1275
Railway Type or Serial Nos.	—	—
Makers of Mechanical Parts	Brown-Boveri	Heap and Rigby
Makers of Electrical Parts	Brown-Boveri	Brown-Boveri
Type of Service	Mixed	Mixed
Axle Classification	$C_0 + C_0$	$B_0 + B_0$
Year First in Service	1932	1927
Total Number in Service	7	6
Total Weight in Tons	132	32·2
Adhesive Weight in Tons	132	32·2
Weight of Mechanical Parts (tons)	—	21·7
Weight of Electrical Parts (tons)	—	10·5
Overall Length	52′ 6″	31′ 1″
Total Wheelbase	39′ 1″	21′ 11½″
Rigid Wheelbase	13′ 5¼″	7′ 0¾″
Driving Wheel Diameter	45″	36″
Carrying Wheel Diameter	—	—
Traction Motors (No. and Type)	6 single-armature	4 single-armature
Motor Ventilation Details	Forced	1060 c.f.m. per motor
Armature Voltage	1500	635
Total Motor Rated Horse Power — Continuous	—	360
Total Motor Rated Horse Power — One Hour	2520	452
Locomotive Continuous Rating — Speed in m.p.h.	19·6	—
Locomotive Continuous Rating — Tractive Effort (lbs.)	45,250	—
Locomotive One-Hour Rating — Speed in m.p.h.	—	11·2
Locomotive One-Hour Rating — Tractive Effort (lbs.)	—	—
Maximum Tractive Effort (lbs.)	74,000	18,000
Maximum Service Speed (m.p.h.)	40·4	16·8
System of Drive	Nose-suspension	Nose-suspension
Gear Ratio	—	4·48
Roller Bearings used on	None	None
Mechanical Brakes	Air on loco and rolling stock	Air on loco and rolling stock
Control System—Main Circuits	E.P. contactor	Mech. camshaft
Armature Combinations — Series	6 3 2	4 2
Armature Combinations — Parallel	– 2 3	– 2
Total Field Values	—	1 2
Economical Running Speeds	—	3
Values of Reduced Field	—	1
Obtained by	—	Tappings
Additional Circuit Breakers	None	Fitted
Electric Braking	—	Rheostatic
Excitation by	—	Self
Low Tension Supply	—	—
Battery	—	—
Compressors — Number and Type	—	1
Compressors — Motor Volts and Rating	—	1275
Compressors — Capacity cu. ft./min.	—	—
Exhausters — Number and Type	—	—
Exhausters — Motor Volts and Rating	—	—
Exhausters — Capacity cu. ft./min.	—	—
Pantographs—Number and Type	2 single	1 single
Train Heating System	—	None

SOUTH AFRICA S.A. Rlys & Hbrs. 3′ 6″ 3000 Class 3E, 191-218 R.S., H.L. M.V.
Mixed $C_0 + C_0$ 1947 28
109 109 — —
56′ 5″ 42′ 0″ — 48″ —
6 single-armature {2500 c.f.m. per motor 1500 2340 2700
31·6 26,640 29·3 34,000 61,000 65
Nose-suspension 3·087 Motors and axles {Air on loco—Vacuum on stock
E.P. 6 3 2 – 2 3 4 4 4 12 3 Inductive shunts
None None — {2. 110v. 16·5 kw. M.G. sets 110v.
1 110v. 8 h.p. 38 1 110v. 8 h.p. 135
2 single 320kw. elec. boiler

Country	Austria	Austria
Railway	Federal	Federal
Gauge	4′ 8½″	4′ 8½″
Nominal Supply Voltage	15,000v. 16⅔ cycles	15,000v. 16⅔ cycles
Railway Type or Serial Nos.	1570·01 etc.	1670·01 etc.
Makers of Mechanical Parts	Krauss—W.L.	Krauss—W.L.
Makers of Electrical Parts	S.S.W.	S.S.W.
Type of Service	Express	Express
Axle Classification	$1 - D_0 - 1^{(1)}$	$1—D_0—1^{(1)}$
Year First in Service	1925	1928
Total Number in Service	4	29
Total Weight in Tons	92·6	102·4
Adhesive Weight in Tons	65·0	68·9
Weight of Mechanical Parts (tons)	54·0	58·0
Weight of Electrical Parts (tons)	38·6	43·8
Overall Length	45′ 11″	47′ 1½″
Total Wheelbase	36′ 1″	36′ 1″
Rigid Wheelbase	10′ 10″	10′ 2″
Driving Wheel Diameter	53¼″	53¼″
Carrying Wheel Diameter	40½″	40½″
Traction Motors (No. and Type)	4 vertical single-armature 8-pole	8 vertical single-armature 6-pole
Motor Ventilation	2-18 h.p. motor-blower sets	2-23·5 h.p. motor-blower sets
Total Motor Rated Horse Power — Continuous	1650	2110
Total Motor Rated Horse Power — One Hour	2130	2725
Locomotive Continuous Rating — Speed in m.p.h.	39·7	45·1
Locomotive Continuous Rating — Tractive Effort (lbs.)	15,550	17,550
Locomotive One-Hour Rating — Speed in m.p.h.	34·2	40·7
Locomotive One-Hour Rating — Tractive Effort (lbs.)	23,300	25,000
Maximum Tractive Effort (lbs.)	37,500	43,500
Maximum Service Speed (m.p.h.)	53	63
System of Drive	S.S.W. link	S.S.W. link
Gear Ratio	3·82	3·84
Roller Bearings used on	None	None
Mechanical Brakes	Vacuum on locos—Air or vacuum on stock	Air on locos—Air or vacuum on stock
Tap Changer	E.P. contactor	E.P. contactor
Control Gear	E.P.	E.P.
Main Transformer Voltage Tappings	16	10
Intermediate Values obtained by	None	by chokes
Total Running Points	15	19
Transformer Rating (exclud. Heating)	1550kva.	2000kva.
Transformer Cooler	Corrug. on tank Forced air circu.	Corrug. on tank Forced air circu.
Additional Circuit Breakers	Oil	Oil
Electric Braking	None	None
Excitation for Braking	—	—
Low Tension Auxiliary Supply	24v.A.C. 24v.D.C.	24v.A.C. 24v.D.C.
Battery Details	24v.	24v.
Compressors — Number and Type	1 rotary	1 rotary
Compressors — Motor Volts and Rating	—	—
Compressors — Capacity cu. ft./min.	82·5	82·5
Exhausters — Number and Type	2 rotary	2 rotary
Exhausters — Motor Volts and Rating	—	—
Exhausters — Capacity cu. ft./min.	45 and 95	45 and 95
Pantographs—Number and Type	2 single	2 single
Train Heating System	*	*

* From main transformer at 800v. and 1000v. (also 600v. on 1570·01etc.).

AUSTRIA FEDERAL 4′ 8½″ 15,000v. 16⅔ cycles 1170.01 etc. W.L. Elin	AUSTRIA FEDERAL 4′ 8½″ 15,000v. 16⅔ cycles 1170.101 etc. Krauss, W.L. Elin	AUSTRIA FEDERAL 4′ 8½″ 15,000v. 16⅔ cycles 1170.201 etc. W.L. A.E.G., S.S.W. Elin., Br.-Boveri	CENTRAL AMERICA COSTA RICA STATE 4′ 8½″ 15,000v. 20 cycles 1–8 A.E.G A.E.G.
Passenger $B_0 - B_0$ 1927 14	Passenger $B_0 + B_0$ 1929 15	Passenger $B_0 + B_0$ 1934 8 25	Mixed A1A + A1A 1929 8
60·3 60·3 26·9 33·4	67·4 67·4 37·6 29·8	79·0 79·0 47·3 31·7	56 45·5 — —
33′ 9½″ 23′ 3″ 7′ 6½″ 51¼″ —	38′ 7″ 27′ 8″ 9′ 8″ 51¼″ —	42′ 5″ 29′ 7″ 10′ 4″ 53¼″ —	39′ 7″ 27′ 2″ 9′ 6″ 49½″ 27½″
4 single-armature 1 motor with 2 blowers 1085 1340	4 single-armature 1 motor and 2 blowers 1285 1580	4 sin.-arm. 10-pole 2 motor-blower sets 1725 1845 2080 2230	4 single-armature 2 4·95 h.p. motor- blower sets 643 804
24·15 16,800 21·1 23,800 35,200 37	24·6 19,450 21·7 27,250 44,000 43	32·9 32·9 19,400 20,950 29·2 29·2 26,450 28,650 44,000 50	15·5 15,400 13·2 19,600 28,700 31
Sécheron spring 5·867 None Air on locos —Air or vacuum on stock	Sécheron spring 5·867 Motors Only Air on locomotives, air or vacuum on rolling stock	Sécheron spring 4·43 Motors only Air on locomotives, air or vacuum on rolling stock	Nose-suspension 6·06 Motors only Air on locomotives and stock
E.P. contactor E.P. — — 15 850kva. Tubes on tank Forced air circu.	E.P. contactor E.P. — — 17 1100kva. Tubes on tank Forced air circu.	E.P. contactor E.P. 9 by chokes 17 1400kva. 1740kva. Corrug. on tank Forced air circu.	E.M. contactor E.M. 10 None 10 — Oil with radiators
Oil Rheostatic A.C. from line 24v. A.C. 24v. D.C. 24v.	Oil Rheostatic A.C. from line 24v. A.C. 24v. D.C. 24v.	Oil Rheostatic A.C. from line 24v.A.C. 24v.D.C. 24v.	Oil None — 200v.A.C. 24v.D.C. 24v.
1 rotary — 82·5 2 rotary — 45 and 95	1 rotary — 82·5 2 rotary — 45 and 95	1 rotary — 82·5 1 rotary — 95	1 two-stage 200 — — — —
2 single From main	2 single transformer at 800v.	2 single and 1000v.	2 single None

Country	GERMANY	GERMANY
Railway	STATE	STATE
Gauge	4′ 8½″	4′ 8½″
Nominal Supply Voltage	15,000v. 16⅔ cycles	15,000v. 16⅔ cycles
Railway Type or Serial Nos.	E21.01 etc.	E15.01
Makers of Mechanical Parts	A.E.G.	A.B.
Makers of Electrical Parts	A.E.G.	S.S.W.
Type of Service	Express	Express
Axle Classification	$1-D_0-2$(1)	$1-B_0+B_0-1$
Year First in Service	1927	1927
Total Number in Service	2	1
Total Weight in Tons	119·9	102
Adhesive Weight in Tons	74·0	72·5
Weight of Mechanical Parts (tons)	60·2	54·4
Weight of Electrical Parts (tons)	59·6	47·5
Overall Length	54′ 2″	55′ 3″
Total Wheelbase	42′ 6″	45′ 3″
Rigid Wheelbase	5′ 11″	11′ 2″
Driving Wheel Diameter	69″	55″
Carrying Wheel Diameter	39½″	39½″
Traction Motors (No. and Type)	4 twin-armature 8-pole	4 single-armature 10-pole
Motor Ventilation	2 motors and 4 blowers	2 motors and 4 blowers
Total Motor Rated Horse Power — Continuous	2735	3160
Total Motor Rated Horse Power — One Hour	3805	3670
Locomotive Continuous Rating — Speed in m.p.h.	66·5	56·5
Locomotive Continuous Rating — Tractive Effort (lbs.)	15,050	20,450
Locomotive One-Hour Rating — Speed in m.p.h.	54·5	52·5
Locomotive One-Hour Rating — Tractive Effort (lbs.)	25,600	25,700
Maximum Tractive Effort (lbs.)	—	46,200
Maximum Service Speed (m.p.h.)	68	68
System of Drive	Quill and cup	Nose-suspension
Gear Ratio	4·26	3·65
Roller Bearings used on	Motors only	Motors only
Mechanical Brakes	Air on loco and on rolling stock	Air on loco and on rolling stock
Tap Changer	E.M. contactor	E.M. contactor
Control Gear	E.M.	E.M.
Main Transformer Voltage Tappings	7	12
Intermediate Values obtained by	aux. transformer	by chokes
Total Running Points	24	21
Transformer Rating (exclud. Heating)	2000kva.	2100kva.
Transformer Cooler	Air-blast	Forced air and oil circulation
Additional Circuit Breakers	Oil	Oil
Electric Braking	None	None
Excitation for Braking	—	—
Low Tension Auxiliary Supply	200v. A.C., 24v. D.C. from gen. on blow. set	200v. A.C., 24v. D.C. fr. gen. on oil-pump set
Battery Details	24v.	24v.
Compressors — Number and Type	1 2-stage recip.	1 2-stage recip.
Compressors — Motor Volts and Rating	—	—
Compressors — Capacity cu. ft./min.	53	53
Exhausters — Number and Type	—	—
Exhausters — Motor Volts and Rating	—	—
Exhausters — Capacity cu. ft./min.	—	—
Pantographs—Number and Type	2 single	2 single
Train Heating System	800v.–1000v. 250kw.	800v.–1000v. 250kw.

GERMANY STATE 4′ 8½″ 15,000v. 16⅔ cycles E16.101 A.B. S.S.W.	GERMANY STATE 4′ 8½″ 15,000v. 16⅔ cycles E17.101 etc. A.E.G. A.E.G., S.S.W.	GERMANY STATE 4′ 8½″ 15,000v. 16⅔ cycles E18.01 etc. A.E.G. A.E.G.	GERMANY STATE 4′ 8½″ 15,000v. 16⅔ cycles E19.01 etc. A.E.G A.E.G.
Express $1-D_0-1$ 1928 1	Express $1-D_0-1^{(1)}$ 1928 38	Express $1-D_0-1^{(1)}$ 1933 70	Express $1-D_0-1^{(1)}$ 1939 2
105 74·1 57·7 47·2	108 78·5 62·5 45·2	106 79 62 44	113 79 — —
56′ 6″ 42′ 4½″ 20′ 0″ 55″ 39½″	52′ 3″ 40′ 4″ Nil 63″ 39½″	55′ 6″ 42′ 0″ Nil 63″ 39½″	55′ 6″ 42′ 0″ Nil 63″ 43″
4 single-armature 10 pole 2 motors and 4 blowers 3220 3755	4 twin-armature 6 pole 2 motors with 4 blowers 3080 3730	4 single-armature 12-pole 4 motor-double- blower sets 3830 4150	4 twin-armature Forced 5030 5420
59·6 19,750 55·3 24,850 46,200 75	59·6 18,850 54·4 25,100 53,000 75	75·1 18,650 73·4 20,700 46,300 87	100 18,480 100 20,000 60,000 112
Nose-suspension 3·65 Motors only Air on loco and on rolling stock	Quill and cup 5·11 Motors only Air on loco and on rolling stock	Quill and cup 2·794 Motors only Air on loco and on rolling stock	Quill and cup Motors and axles Air on loco and on rolling stock
E.M. contactor E.M. 12 by chokes 21 2100kva. Air-blast	E.M. contactor E.M. 11 by chokes 21 1950kva. Air-blast	Motor camshaft E.P. 15 Revers. booster 15 2920kva. Tubes on tank Forced air circu.	Motor camshaft E.P. 15 Revers. booster 15 — Tubes on tank
Oil None — 200v. A.C., 24v. D.C. from gen. on blow. set 24v.	Oil None — 200v. A.C. 24v. D.C. from gen. on blow. set 24v.	Air-blast None — 200v. A.C. 24v. D.C. 24v. charged	Air-blast None — 200v. A.C. 24v. D.C. through rectifier
1 2-stage recip. — 53 — — —	1 2-stage recip. — 53 — — —	1 2-stage recip. — 53 — — —	1 2-stage — 53 — — —
2 single From	2 single main transformer at	2 single 800v. and 1000v.	2 single 250kw.

Country	GERMANY	GERMANY
Railway	STATE	STATE
Gauge	4′ 8½″	4′ 8½″
Nominal Supply Voltage	15,000v. 16⅔ cycles	15,000v. 16⅔ cycles
Railway Type or Serial Nos.	E04·01 etc.	E05·001, 002, 103
Makers of Mechanical Parts	A.E.G.	H.S.
Makers of Electrical Parts	A.E.G.	S.S.W.
Type of Service	Passenger	Passenger
Axle Classification	$1-C_0-1$	$1-C_0-1$
Year First in Service	1932	1933
Total Number in Service	23	3
Total Weight in Tons	90·5	89·0
Adhesive Weight in Tons	60·4	58·5
Weight of Mechanical Parts (tons)	53·6	53·5
Weight of Electrical Parts (tons)	36·9	35·5
Overall Length	49′ 7″	50′ 6″
Total Wheelbase	38′ 1″	37′ 5″
Rigid Wheelbase	—	19′ 0″
Driving Wheel Diameter	63″	55½″
Carrying Wheel Diameter	39½″	39½″
Traction Motors (No. and Type)	3 single-armature 12-pole	3 single-armature 10 pole
Motor Ventilation	3 motor-double-blower sets	2 motors and 3 blowers
Total Motor Rated Horse Power — Continuous	2820	2410
Total Motor Rated Horse Power — One Hour	2940	2895
Locomotive Continuous Rating — Speed in m.p.h.	54 63·5	68·5 79·8
Locomotive Continuous Rating — Tractive Effort(lbs.)	19,100 16,200	12,850 11,050
Locomotive One-Hour Rating — Speed in m.p.h.	52·2 60·3	61·0 71·5
Locomotive One-Hour Rating — Tractive Effort(lbs.)	20,550 17,750	17,350 14,800
Maximum Tractive Effort (lbs.)	39,700 34,200	— —
Maximum Service Speed (m.p.h.)	68 81	68 81
System of Drive	Quill and cup	Nose-suspension
Gear Ratio	3·414 2·939	3·71 3·18
Roller Bearings used on	Motors only	Motors only
Mechanical Brakes	Air on loco and on rolling stock	Air on loco and on rolling stock
Tap Changer	Motor camshaft	Motor camshaft
Control Gear	E.P.	E.P.
Main Transformer Voltage Tappings	15	15
Intermediate Values obtained by	Revers. booster	Revers. booster
Total Running Points	15	15
Transformer Rating (exclud. Heating)	1400kva.	1500kva.
Transformer Cooler	Tubes on tank Forced air circu.	Separate cooler
Additional Circuit Breakers	Oil	Air-blast
Electric Braking	None	None
Excitation for Braking	—	—
Low Tension Auxiliary Supply	200v. A.C., 24v. D.C. from gen. on blow. set	200v. A.C., 24v. D.C. from battery
Battery Details	24v.	24v. ch. thro' rect.
Compressors — Number and Type	1 2-stage recip.	1 2-stage recip.
Compressors — Motor Volts and Rating	—	—
Compressors — Capacity cu. ft./min.	53	59
Exhausters — Number and Type	—	—
Exhausters — Motor Volts and Rating	—	—
Exhausters — Capacity cu. ft./min.	—	—
Pantographs—Number and Type	2 single	2 single
Train Heating System	600, 800, 1000v.	250 kw.

GERMANY STATE 4′ $8\frac{1}{2}$″ 15,000v. $16\frac{2}{3}$ cycles E44·002 etc. H.S. S.S.W.	GERMANY STATE 4′ $8\frac{1}{2}$″ 15,000v. $16\frac{2}{3}$ cycles E44·502 etc. A.E.G. A.E.G.	GERMANY STATE 4′ $8\frac{1}{2}$″ 15000v. $16\frac{2}{3}$ cycles E95·01 etc. A.E.G. A.E.G., S.S.W.	GERMANY STATE 4′ $8\frac{1}{2}$″ 15,000v. $16\frac{2}{3}$ cycles E93·01 etc. A.E.G. A.E.G.
Mixed $B_0 + B_0$ 1933 110	Mixed $B_0 + B_0$ 1933 8	Freight $1 - C_0 + C_0 - 1$ 1927 6	Freight $C_0 + C_0$ 1933 18
76 76 42·4 33·6	78·4 78·4 39·6 38·7	136 114 72·5 63·5	115·5 115·5 69·1 46·4
50′ 1″ 32′ 3″ 11′ 6″ $49\frac{1}{4}$″ —	46′ 10″ 31′ 9″ 11′ 2″ $49\frac{1}{4}$″ —	68′ 6″ 51′ 9″ 15′ 1″ 55″ $33\frac{1}{2}$″	58′ 0″ 42′ 0″ 14′ 5″ $49\frac{1}{4}$″ —
4 single-armature 8-pole 2 motor-blower sets 2470 2950	4 single-armature 10-pole 2 motor-blower sets 2690 2950	6 single armature 8-pole 2 motors with 6 blows. each 3900 c.f.m. 3220 3720	6 single-armature 8-pole 3 motors and 6 blowers 2960 3350
49·6 18,200 47·2 22,800 53,000 56	42·5 44·5 23,150 22,100 39·1 42·5 27,550 25,400 58,000 54,000 50 56	30·4 38,700 29·0 46,900 79,500 43	38·8 27,950 35·7 34,400 79,500 43
Nose-suspension 4·61 Motors only Air on loco and on rolling stock	Nose-suspension 4·21 3·95 Motors only Air on loco and on rolling stock	Nose-suspension 5·294 Motors only Air on loco and on rolling stock	Nose-suspension 5·375 Motors only Air on loco and on rolling stock
Motor camshaft E.P. 15 Revers. booster 15 1450 kva. 2 separate coolers	Motor camshaft E.P. 15 Revers. booster 15 1440 kva. Forced	E.M. contactor E.P. 14 Trans. out of step 25 1020 each (2) Tubes on tank air and oil circ	Motor camshaft E.P. 15 Revers. booster 15 1680 Tubes on tank ulations
Air-blast None — 200v. A.C., 24v. D.C. from battery 24. ch. thro, rect.	Oil None — 200v. A.C., 24v. D.C. from gen. on blower set 24v.	Oil None — 200v. A.C., 24v. D.C. from gen. on blow. set 24v.	Oil None — 200v. A.C., 24v. D.C. from gen. on blow. set 24v.
1 2-stage recip. — 59 — — —	1 2-stage recip. — 59 — — —	1 2-stage recip. — 53 — — —	1 2-stage recip. — 53 — — —
2 single From	2 single main transformer	2 single at 800v. and 1000	2 single v. 250kw.

Country	GERMANY	GERMANY
Railway	STATE	STATE
Gauge	4′ 8½″	4′ 8½″
Nominal Supply Voltage	20,000v. 50 cycles	20,000v. 50 cycles
Railway Type or Serial Nos.	E244·01	E244·11
Makers of Mechanical Parts	A.E.G.	K.M.
Makers of Electrical Parts	A.E.G.	Brown-Boveri
Type of Service	Mixed	Mixed
Axle Classification	$B_0 + B_0$	$B_0 + B_0$
Year First in Service	1936	1936
Total Number in Service	1	1
Total Weight in Tons	83·5	83·2
Adhesive Weight in Tons	83·5	83·2
Weight of Mechanical Parts (tons)	43·2	44·2
Weight of Electrical Parts (tons)	40·3	39·0
Overall Length	47′ 0″	50′ 2″
Total Wheelbase	31′ 10″	32′ 2″
Rigid Wheelbase	11′ 2″	11′ 6″
Driving Wheel Diameter	49½″	49½″
Carrying Wheel Diameter	—	—
Traction Motors (No. and Type)	4 single-armature D.C. series type 1700v. max.	4 single-armature D.C. series type 800v. max.
Motor Ventilation	2 motors and 4 blowers	4 motor-blower sets
Total Motor Rated Horse Power — Continuous	2305	2845
Total Motor Rated Horse Power — One Hour	2680	3000
Locomotive Continuous Rating — Speed in m.p.h.	37·0	37·0
Locomotive Continuous Rating — Tractive Effort (lbs.)	22,800	28,100
Locomotive One-Hour Rating — Speed in m.p.h.	37·0	37·0
Locomotive One-Hour Rating — Tractive Effort (lbs.)	26,500	29,600
Maximum Tractive Effort (lbs.)	53,000	53,000
Maximum Service Speed (m.p.h.)	53	53
System of Drive	Nose-suspension	Nose-suspension
Gear Ratio	4·5	3·59
Roller Bearings used on	Motors only	Motors only
Mechanical Brakes	Air on loco and on rolling stock	Air on loco and on rolling stock
Tap Changer / Control Gear	Grid-controlled rectifier series-parallel	Rectifier with H.T. tap-changer
Main Transformer Voltage Tappings / Intermediate Values obtained by	motor connections and field weakening	giving 28 voltages
Total Running Points	7	28
Transformer Rating (exclud. Heating)	2160kva.	1980kva.
Transformer Cooler	Separate cooler	Separate cooler
Additional Circuit Breakers	Air-blast	Oil
Electric Braking	Rheostatic	Rheostatic
Excitation for Braking	From rectifier	Self
Low Tension Auxiliary Supply	200v. 3-ph. A.C. from convertor 24v. D.C.	220v. D.C. from rect. 24v. from battery
Battery Details	24v.	24v.
Compressors — Number and Type	1 2-stage recip.	1 2-stage recip.
Compressors — Motor Volts and Rating	—	—
Compressors — Capacity cu. ft./min.	59	59
Exhausters — Number and Type	—	—
Exhausters — Motor Volts and Rating	—	—
Exhausters — Capacity cu. ft./min.	—	—
Pantographs—Number and Type	2 single	2 single
Train Heating System	800v.–1000v. 400kw.	800v.–1000v. 320kw.

GERMANY STATE 4′ 8½″ 20,000v. 50 cycles E244·21 K.M. S.S.W.	GERMANY STATE 4′ 8½″ 20,000v. 50 cycles E244·31 Krupp Krupp, G.L.	NORWAY STATE 4′ 8½″ 15,000v. 16⅔ cycles EL 1b Thunes Per Kure	NORWAY STATE 4′ 8½″ 15,000v. 16⅔ cycles EL 3 Thunes, Hamar A.E.G., S.S.W.
Mixed $B_0 + B_0$ 1936 1	Mixed $B_0 - B_0$ 1936 1	Mixed B + B 1930 2	Freight 1 − C + C − 1 1925 5
83·5 83·5 43·0 40·5	81·7 81·7 42·3 39·4	62 62 39·5 22·5	138·3 107 78·8 59·5
54′ 0″ 33′ 7″ 11′ 6″ 49¼″ —	49′ 6″ 32′ 9″ 10′ 10″ 49¼″ —	41′ 8″ 28′ 10″ 9′ 9″ 57″ —	69′ 4″ 54′ 10″ 16′ 2¼″ 60½″ 38⅞
8 single-phase ser. comm. 14-pole sin.-arm. 270v. max. 2 motor-blower sets 2435 2640	4 single-phase 4 three-phase (2) all single armature 4 motor-blow. sets (1-phase) (3-phase) 2630 2575 2840 2705	two two blowers 810 940	four two blowers 2500 2900
37·0 24,050 37·0 26,100 53,000 53	35·4 — 35·6 — 53,000 53	28·0 12,380 23·8 16,240 32,230 43·5	27·4 27,180 22·5 41,500 70,150 37·5
Nose-suspension 5·867 Motors only Air on loco and on rolling stock	Nose-suspension 3·8 4·07 Motors only Air on loco and on rolling stock	Siderod 4·27 None Air on loco and on rolling stock	Siderod 4·83 None Air on loco and on rolling stock
Manual camshaft } E.P. contactor } 14 Revers. booster 14 1720kva. Seperate cooler	See chap. 7 on German indus. frequency locos 1 Rotor resistance 3 1900kva. Seperate cooler	E.M. contactor E.M. } Auto-transformer 239–1000v. 18 600kva. Forced air circu.	E.M. contactor E.M. } Two auto-transf. 0–555v. 14 1155kva. each Forc. air and oil circu.
Air-blast Rheostatic 2 motors used as gens. 20v. A.C. 20v. D.C. from battery 24v. ch. thro' rect.	Air-blast Regenerative — 220v. 3ph. A.C., 24v. D.C. 24v.	— None — 210v. A.C. —	— None — 220v. A.C. —
1 2-stage recip. — 59 — — —	1 2-stage recip. — 59 — — —	1 2-stage rotary 210v. 10 h.p. 55 — — —	2 2-stage rotary 220v. 23·8 h.p. 72·2 — — —
2 single 800v.–1000v. 320kw.	2 single 800v.–1000v. 320kw.	2 single 800v. and 1000v.	2 single None

Country	Norway	Norway
Railway	State	State
Gauge	4′ 8½″	4′ 8½″
Nominal Supply Voltage	15,000v. 16⅔ cycles	15,000v. 16⅔ cycles
Railway Type or Serial Nos.	EL4	EL5
Makers of Mechanical Parts	Thunes Hamar	Thunes
Makers of Electrical Parts	N.E. and B.B.	A.E.G., N.E. & B.B., S.S.W. Per Kure
Type of Service	Freight	Mixed
Axle Classification	1 – C + C – 1	B + B
Year First in Service	1925	1927
Total Number in Service	3	12
Total Weight in Tons	134·5	67
Adhesive Weight in Tons	104	67
Weight of Mechanical Parts (tons)	75·5	39·4
Weight of Electrical Parts (tons)	59·0	27·6
Overall Length	64′ 4″	43′ 0″
Total Wheelbase	54′ 10″	29′ 8½″
Rigid Wheelbase	15′ 2½″	10′ 5″
Driving Wheel Diameter	60¼″	60¼″
Carrying Wheel Diameter	38⅞″	—
Traction Motors (No. and Type)	2 twin-armature	2 single-armature
Motor Ventilation	4 blowers	2 blowers
Total Motor Rated Horse Power — Continuous	2320	1160
Total Motor Rated Horse Power — One Hour	2800	1400
Locomotive Continuous Rating — Speed in m.p.h.	27·4	28·5
Locomotive Continuous Rating — Tractive Effort (lbs.)	32,440	15,020
Locomotive One-Hour Rating — Speed in m.p.h.	25·0	26·8
Locomotive One-Hour Rating — Tractive Effort (lbs.)	41,500	18,300
Maximum Tractive Effort (lbs.)	68,400	31,580
Maximum Service Speed (m.p.h.)	37·5	43·5
System of Drive	Geared jackshaft	Siderod
Gear Ratio	3·22	3·79
Roller Bearings used on	None	None
Mechanical Brakes	Air on loco and rolling stock	Air on loco and rolling stock
Tap Changer	Motor-driven sliding contact	E.M. contactor
Control Gear	E.M.	E.M.
Main Transformer Voltage Tappings Intermediate Values obtained by	Two-auto-transfs. 0–1230v.	Auto transformer 0–1040v.
Total Running Points	18	15
Transformer Rating (exclud. Heating)	2070kva. each	1100kva.
Transformer Cooler	Forc. air and oil circu.	Forc. air and oil circu.
Additional Circuit Breakers	—	—
Electric Braking	None	None
Excitation for Braking	—	—
Low Tension Auxiliary Supply	220v. A.C.	210v. A.C.
Battery Details	—	—
Compressors — Number and Type	2 2-stage rotary	1 2-stage recip.
Compressors — Motor Volts and Rating	220v. 22 h.p.	210v. 18·5 h.p.
Compressors — Capacity cu. ft./min.	73·2	68·5
Exhausters — Number and Type	—	—
Exhausters — Motor Volts and Rating	—	—
Exhausters — Capacity cu. ft./min.	—	—
Pantographs—Number and Type	2 single	2 single
Train Heating System	800v. and 1000v.	800v. and 1000v.

NORWAY STATE 4′ 8½″ 15,000v. 16⅔ cycles EL8 Thunes N.E. and B.B., Per Kure	NORWAY STATE 4′ 8½″ 15,000v. 16⅔ cycles EL9 Thunes N.E. and B.B., Per Kure	SWEDEN GOTHENBURG–BORAS 4′ 8½″ 15,000v. 16⅔ cycles 1 etc. A.B.M.V., A.B.N.H. A.S.E.A.	SWEDEN STATE 4′ 8½″ 16,000v. 16⅔ cycles D — A.S.E.A.
Passenger $1-D_0-1^{(1)}$ 1940 11	Mixed B_0+B_0 1946 3	Mixed B_0-B_0 1937 9	Mixed 1 – C – 1 1925 281
82·8 60 — —	48 48 — —	68·0 68·0 35 33	79·5 50·4 50 29·4
45′ 4″ 33′ 1½″ 5′ 11″ 53″ 38⅞″	33′ 6″ 20′ 7½″ 7′ 2½″ 39⅜″ —	39′ 0″ 26′ 3″ 9′ 2″ 41¾″ —	42′ 7″ 30′ 10″ 17′ 8″ 60¼″ 38″
4 single-armature 2 motor-blower sets 2500 2828	4 single-armature 1 motor-blower set 900 1000	4 single-armature Forced 1400 1600	1 twin-armature 1 motor with two blowers 1770 1975
47·3 18,340 44·1 22,300 40,400 68·5	23·3 13,250 21·5 16,100 26,500 31	44 29 12,000 18,000 41 27 14,300 21,000 26,500 35,300 62 42	— — 43·3 16,700 37,500 62
Quill and cup 3·25 Motors only Air on loco and rolling stock	Nose-suspension 5·94 Motors only Air on loco and stock	Sécheron spring 3·62 5·46 Motors only Air on locos—Vacuum on stock	Siderod 3·19 4·24 None Air on locos and stock
Motor-dr. prim. tap-changer — } Auto-transformer 0–1000v. 28 2260 kva. Forc. air and oil circu.	Motor-dr. prim. tap-changer — } Auto-transformer 0–1000v. 28 925 kva. Forc. air and oil circu.	Contactor Contactor 6 Aux transf. 16 1350 kva. Seperate cooler	E.M. contactor E. M. cont. & reversers 6 Aux transf. 16 1230 kva. Seperate cooler
Oil None — 210v. A.C. —	Oil Rheostatic D.C. from M.G.set 200v. A.C. 6·5v. D.C. 150AH.	Oil None — — —	Oil None — 216v.–247v. A.C. and 24v. 24v. for lighting
1 2-stage recip. 210v. 25·8 h.p. 77 — — —	1 reciprocating 200v. 6·8 h.p. 25·6 — — —	1 reciprocating — — 1 rotary — —	1 reciprocating — — — — —
2 single 800v. and 1000v.	1 single 800v. and 1000v.	2 single 1000v.	2 double 600v. 800v. 1000v.

Country	SWEDEN	SWEDEN
Railway	STATE	STATE
Gauge	4′ 8½″	4′ 8½″
Nominal Supply Voltage	16,000v. 16⅔ cycles	16,000v. 16⅔ cycles
Railway Type or Serial Nos.	Ud	F
Makers of Mechanical Parts	—	A.B.M.V., A.B.N.H. S.S. Rlys.
Makers of Electrical Parts	A.S.E.A.	A.S.E.A.
Type of Service	Mixed	Passenger
Axle Classification	$B_0 - B_0$	$1 - D_0 - 1$ (1)
Year First in Service	1936	1942
Total Number in Service	27	3
Total Weight in Tons	49·5	100
Adhesive Weight in Tons	49·5	64
Weight of Mechanical Parts (tons)	23	59
Weight of Electrical Parts (tons)	26·5	41
Overall Length	37′ 0″	50′ 0″
Total Wheelbase	26′ 6″	38′ 0″
Rigid Wheelbase	8′ 2½″	22′ 0″
Driving Wheel Diameter	38¾″	60″
Carrying Wheel Diameter	—	39″
Traction Motors (No. and Type)	4 single-armature	4 single-armature
Motor Ventilation	1 motor-blower set	225v. 12·7 h.p. motor-blower sets
Total Motor Rated Horse Power — Continuous	1400	2820
Total Motor Rated Horse Power — One Hour	1600	3325
Locomotive Continuous Rating — Speed in m.p.h.	—	32·0
Locomotive Continuous Rating — Tractive Effort (lbs.)	—	23,100
Locomotive One-Hour Rating — Speed in m.p.h.	36·3	32·0
Locomotive One-Hour Rating — Tractive Effort (lbs.)	15,450	26,650
Maximum Tractive Effort (lbs.)	26,500	38,500
Maximum Service Speed (m.p.h.)	56	85
System of Drive	Nose-suspension	Quill and cup or Quill and spring
Gear Ratio	—	—
Roller Bearings used on	Motors and axles	—
Mechanical Brakes	Air on loco and on rolling stock	Air on loco and on rolling stock
Tap Changer	E.M. contactor	H.T. or L.T.
Control Gear	E.M. con.E.P. rev.	—
Main Transformer Voltage Tappings	5	—
Intermediate Values obtained by	Aux. trans.	—
Total Running Points	13	28–62
Transformer Rating (exclud. Heating)	—	—
Transformer Cooler	Separate cooler	Motor-dr. blower
Additional Circuit Breakers	Oil	Fitted
Electric Braking	None	None
Excitation for Braking	—	—
Low Tension Auxiliary Supply	216–247v. & 24v. A.C.	A.C. & D.C. up to 72v.
Battery Details	24v. for lighting	—
Compressors — Number and Type	1 reciprocating	1 reciprocating
Compressors — Motor Volts and Rating	—	—
Compressors — Capacity cu. ft./min.	—	—
Exhausters — Number and Type	—	—
Exhausters — Motor Volts and Rating	—	—
Exhausters — Capacity cu. ft./min.	—	—
Pantographs—Number and Type	2 double	2 single
Train Heating System	600v. 800v. 1000v.	800v. and 1000v. A.C.

Switzerland	Switzerland	Switzerland	Switzerland
	Berne, Loets	chberg-Simplon	
4′ 8½″ 15,000v. 16⅔ cycles Ae6/8 201 etc. Breda, S.L.M. Sécheron	4′ 8½″ 15,000v. 16⅔ cycles Ae5/7 171 S.L.M. Oerlikon	4′ 8½″ 15,000v. 16⅔ cycles Ae4/4 251 etc. S.L.M. Brown-Boveri	4′ 8½″ 15,000v. 16⅔ cycles Ee3/3 401 S.L.M. Sécheron
Mixed $1-C_0+C_0-1$ 1939 8	Mixed 1 – E – 1 1942 (rebuild) 1	Passenger B_0-B_0 1944 2	Shunting C 1943 1
140 112·5 77 63	97 76·2 58 39	78·5 78·5 — —	40 40 30 10
66′ 6″ 54′ 6″ 13′ 4½″ 53¾″ 37⅜″	52′ 5″ 37′ 3″ 24′ 1″ 53″ 33½″	51′ 2″ 37′ 8″ 10′ 8″ 49″ —	30′ 1″ 13′ 3″ 13′ 3″ 41″ —
6 twin-arm. 6-pole 2 blowers each 17000 c.f.m. to motors & transform. 5130 6000	4 single-armature blowers — 3000	4 single-armature 2 blowers 3300 3880	1sin.- arm. 10-pole 1 blower 32000 c.f.m. 580 615
38·5 49,500 35 62,500 79,000 53	— — 37·3 27,250 44,800 56	— — 46·3 30,500 48,500 77·5	19·4 11,200 22·0 12,200 20,000 25
Sécheron- Meyforth 5·312 None Air on loco and on rolling stock	Scotch-yoke and siderod 9·87 Motors Air on loco and on rolling stock	Br.-Bov. disc drive 2·22 Motors and axles Air on loco and on rolling stock	Jackshaft- siderod 5·5625 None Air on loco and on rolling stock
Mech.-pneu. cont. E.P. 12 by 3 preven. coils 24 2500/3800 kva. Forced air thro' oil	— — — — — — —	H.T. con. (B.B. Type) E.P. — — 28 — Forced oil circu.	E.P. contactors E.P. 15 1 preventive coil 15 300 kva. nat. cool. tube-tank
1 main oil switch Rheostatic Transformer 220v.A.C. 36v.D.C. 36v. 90AH. Nick-Cad.	Fitted — — — —	— Regenerative — 220v.A.C.36v.D.C. 36v. 100AH.	— None — 220v. A.C. 36v. D.C. 36v. 90 AH. Nick-Cad.
2 rotary 220v. 15 h.p. 45 — — —	Fitted — — — — —	1 rotary 220v. 95 — — —	1 rotary 220v. 15 h.p. 45 — — —
2 single 1000v. A.C.	2 single 1000v. A.C.	2 single 1000v. A.C.	1 single 1000v. A.C.

Country	SWITZERLAND	SWITZERLAND
Railway	Bodensee-Toggenburg	Emmen.-Burg.-Thun
Gauge	4′ 8½″	4′ 8½″
Nominal Supply Voltage	15,000v. 16⅔ cycles	15,000v.16⅔ cycles
Railway Type or Serial Nos.	—	EBT. SMB 101 etc.
Makers of Mechanical Parts	S.L.M.	S.L.M.
Makers of Electrical Parts	Sécheron	Sécheron, Br.-Boveri, Oerlikon
Type of Service	Mixed	Mixed
Axle Classification	$B_0 + B_0$	$B_0 - B_0$
Year First in Service	1931	1932
Total Number in Service	6	8
Total Weight in Tons	61	63·8
Adhesive Weight in Tons	61	63·8
Weight of Mechanical Parts (tons)	32·5	35·8
Weight of Electrical Parts (tons)	28·5	28·0
Overall Length	39′ 4″	40′ 8″
Total Wheelbase	28′ 8″	29′ 2½″
Rigid Wheelbase	9′ 6¼″	9′ 6¼″
Driving Wheel Diameter	41″	63″
Carrying Wheel Diameter	—	—
Traction Motors (No. and Type)	4 single-armature	4 single-armature
Motor Ventilation	19,750 c.f.m. to motors and to transformer	19,750 c.f.m. to motors and to transformer
Total Motor Rated Horse Power — Continuous	1440	1440
Total Motor Rated Horse Power — One Hour	1600	1600
Locomotive Continuous Rating — Speed in m.p.h.	34·2	31·0
Locomotive Continuous Rating — Tractive Effort(lbs.)	15,550	17,100
Locomotive One-Hour Rating — Speed in m.p.h.	34·2	31·0
Locomotive One-Hour Rating — Tractive Effort(lbs.)	17,300	19,030
Maximum Tractive Effort (lbs.)	29,100	27,350
Maximum Service Speed (m.p.h.)	49·7	46·6
System of Drive	Sécheron qui	ll and springs
Gear Ratio	4·2	4·533
Roller Bearings used on	None	motors only
Mechanical Brakes	Air on locos and	on rolling stock
Tap Changer	E.P. contactors	E.P. contactors
Control Gear	E.P.	E.P.
Main Transformer Voltage Tappings	8	8
Intermediate Values obtained by	3 preventive coils	3 preventive coils
Total Running Points	15	15
Transformer Rating (exclud. Heating)	1000kva.	1000kva
Transformer Cooler	Oil cooled by f	orced ventilation
Additional Circuit Breakers	1 oil	1 oil
Electric Braking	None	None
Excitation for Braking	—	—
Low Tension Auxiliary Supply	220v. A.C. 36v. D.C.	220v. A.C. 36v. D.C.
Battery Details	36v. 90AH lead-acid	36v. 90AH. lead-acid
Compressors — Number and Type	1 rotary	1 rotary
Compressors — Motor Volts and Rating	220v. 23 h.p.	220v. 23 h.p.
Compressors — Capacity cu. ft./min.	29·7	29·7
Exhausters — Number and Type	—	—
Exhausters — Motor Volts and Rating	—	—
Exhausters — Capacity cu. ft./min.	—	—
Pantographs—Number and Type	2 single	2 single
Train Heating System	1000v. A.C.	1000v. A.C.

SWITZERLAND FEDERAL 4′ 8½″ 15,000v. $16\frac{2}{3}$ cycles Ae 4/7 10901 etc. S.L.M. Sécheron, Br.- Boveri, Oerlikon	SWITZERLAND FEDERAL 4′ 8½″ 15,000v. $16\frac{2}{3}$ cycles Ae 8/14 11801 S.L.M. Brown-Boveri	SWITZERLAND FEDERAL 4′ 8½″ 15,000v. $16\frac{2}{3}$ cycles Ae 8/14 11851 S.L.M. Oerlikon	SWITZERLAND FEDERAL 4′ 8½″ 15,000v. $16\frac{2}{3}$ cycles Ae 8/14 11852 S.L.M. Oerlikon
Express $1-D_0-2$ 1927 16 81 30	Mixed $1-B_0-1-B_0-1$(1) $+1-B_0-1-B_0-1$ 1932 1	Mixed $1-B_0-1-B_0-1$(1) $+1-B_0-1-B_0-1$ 1932 1	Mixed $1-B_0-1-B_0-1$(1) $+1-B_0-1-B_0-1$ 1939 1
116·3 116-120 121·3 75·8 76-78 78·1 62 — 65 54 — 56	242 156·8–169·4(3) 127 115	240·2 156–169(3) 120 120	232 157·5(3) 117·7 114·3
55′ 0″ 55′ 0″ 56′ 0″ 41′ 7″ 7′ 2½″ 63½″ 37½″	111′ 6″ 95′ 0″ — 63½″ 37½″	111′ 6″ 95′ 0″ — 53¼″ 37½″	111′ 4″ 95′ 4½″ — 53″ 37¼″
4 sin-arm. 16-pole 2. 28 h.p. motors with 4 blowers each 5300 c.f.m. 2270 3155 3155 2760 3255 3255	8 sin-arm. 16-pole 4 motors and 8 blowers 6905 7400	16 sin-arm. 10-pole 8 motor-blower sets 8185 8680	16 single-arm. 8 blowers 10800 11400
41·5 20,000 27,800 27,800 40·4 25,600 28,650 28,650 44,000 62	40·4 64,000 36·6 75,500 110,000 62	40·4 76,000 38·5 84,500 134,000 62	47·5 84,000 46·3 88,000 110,000 68
Buchli link 2·57 None Air	Buchli link 2·57 None on Locomotives	Winterthur Univ. 3·47 None and on rolling	Winterthur Univ. 3·47 None stock
Sliding con. or E.P. con. E.P. 7 aux. trans. 21 2700 kva. Tubes on loco frame	Sliding contact* E.P. 28 By alterna 56 2 2900 kva. each Separate cooler	Sliding contact* E.P. 28 te operation of tap 56 2 2900 kva. each Separate cooler	H.T. control-Oerlikon E.P. 29 -changers 29 2 3650 kva. each Oil circulation
1 oil None regen. — transform 220v. A.C. 36v. D.C. 36v. D.C.	2 oil per comp Regenerative A.C. 220v. A.C. 36v. D.C. fr. gen. on blow-set 36v.	lete locomotive 26,500 lbs. T.E. from main transfo 220v. A.C. 36v. D.C. fr. gen. on blow-set 36v.	— Regenerative rmer 220v. A.C. 36v. D.C. Two 36v. 100AH
1 rotary or recip. — 105 — — —	1 rotary — 105 — — —	1 reciprocating — 105 — — —	2 rotary 220v. 80 — — —
2 single 800v. & 1000v. A.C.	4 single 800v. and 1000v.	4 single from main trans.	2 single 1000v. A.C.

* With sep. arcing contacts on H.T. winding of special transformers.

Country	Switzerland	Switzerland
Railway	Federal	Federal
Gauge	4′ 8½″	4′ 8½″
Nominal Supply Voltage	15,000v. 16⅔ cycles	15,000v. 16⅔ cycles
Railway Type or Serial Nos.	Ae 4/6 10,801 etc.	RFe 4/4 601 etc.
Makers of Mechanical Parts	S.L.M.	S.L.M.
Makers of Electrical Parts	Sécheron, Br.-Boveri, Oerlikon	Oerlikon
Type of Service	Mixed	Passenger
Axle Classification	$1-D_0-1^{(1)}$	B_0-B_0
Year First in Service	1941	1941
Total Number in Service	12	3
Total Weight in Tons	104	46·2
Adhesive Weight in Tons	78·5	46·2
Weight of Mechanical Parts (tons)	55·2	28·3
Weight of Electrical Parts (tons)	48·6	17·9
Overall Length	56′ 6½″	51′ 10″
Total Wheelbase	40′ 0″	40′ 11½″
Rigid Wheelbase	10′ 6″	8′ 10½″
Driving Wheel Diameter	53″	35⅜″
Carrying Wheel Diameter	37¼″	—
Traction Motors (No. and Type)	8 single-armature	4 single-armature
Motor Ventilation	4 blowers	2 blowers
Total Motor Rated Horse Power — Continuous	5230	1250
Total Motor Rated Horse Power — One Hour	5540	1340
Locomotive Continuous Rating — Speed in m.p.h.	54·0	57·5
Locomotive Continuous Rating — Tractive Effort (lbs.)	35,000	8,000
Locomotive One-Hour Rating — Speed in m.p.h.	52·5	56·0
Locomotive One-Hour Rating — Tractive Effort (lbs.)	39,000	8,600
Maximum Tractive Effort (lbs.)	61,500	14,000
Maximum Service Speed (m.p.h.)	77·5	77·5
System of Drive	Winterthur Universal	Br.-Bov. flexible drive
Gear Ratio	3·22	3·17
Roller Bearings used on	None	motors and axles
Mechanical Brakes	Air on loco and on rolling stock	Air on loco and on rolling stock
Tap Changer	H.T. control (Brown-Boveri)	E.P. contactors
Control Gear	E.P.	—
Main Transformer Voltage Tappings	—	—
Intermediate Values obtained by	—	—
Total Running Points	—	—
Transformer Rating (exclud. Heating)	—	—
Transformer Cooler	Oil circulation	Oil circulation
Additional Circuit Breakers	—	—
Electric Braking	Regenerative	Rheostatic
Excitation for Braking	Transformer	Transformer
Low Tension Auxiliary Supply	220v. A.C. 36v. D.C.	220v. A.C. 36v. D.C.
Battery Details	36v. 100AH.	36v. 100AH.
Compressors — Number and Type	1 rotary	1 rotary
Compressors — Motor Volts and Rating	220v.	220v.
Compressors — Capacity cu. ft./min.	95	45
Exhausters — Number and Type	—	—
Exhausters — Motor Volts and Rating	—	—
Exhausters — Capacity cu. ft./min.	—	—
Pantographs—Number and Type	2 single	2 single
Train Heating System	1000v. A.C.	1000v. A.C.

SWITZERLAND FEDERAL 4′ 8½″ 15,000v. 16⅔ cycles Re 4/4 401 etc. S.L.M. Sécheron, Br.- Boveri, Oerlikon	SWITZERLAND FEDERAL (BRÜNIG) 3′ 3⅜″ 15,000v. 16⅔ cycles Fhe 4/6 901 etc. S.L.M. Sécheron, Br.- Boveri, Oerlikon	SWITZERLAND FEDERAL 4′ 8½″ 15,000v. 16⅔ cycles 15301 etc. S.L.M. Brown-Boveri	SWITZERLAND FEDERAL 4′ 8½″ 15,000v. 16⅔cycles 16311, 16331 etc. S.L,M. Brown-Boveri
Passenger $B_0 - B_0$ 1946 16	Mixed $B_0 - 2 - B_0$ 1941 16	Freight C – C 1926 3	Shunting C 1928 16
55 55 — —	55·1 39·3 32·3 22·8	73 73 45 28	45 45 — —
48′ 2″ 35′ 5″ — 41″ —	47′ 10¼″ 39′ 1″ 8′ 2½″ 35½″ 28″	45′ 11″ 35′ 5″ 13′ 3½″ 41″ —	30′ 0″ 13′ 3½″ 13′ 3½″ 41″ —
4 single-armature 2 blowers 2170 2220	4 adhesion 2 rack 1 blower (Adh.) (Rack) 1100 1140 1215 1270	2 single-armature 2 motor-blower sets 1000 1200	1 single-armature 1 motor-blower set 575 690
55·0 14,500 46·5 17,600 31,000 77·5	33 16·7 12,000 26,000 32 16 14,000 29,500 23,000 48,500 46·5 20·5	18·0 18,950 18·0 22,720 39,700 25	17·8 10,600 17·8 12,670 19,850 25
Br.-Bov. flexible drive — motors and axles Air on loco and on rolling stock	Nose-susp. Double reduction 5·31 11·42 motors and axles Air on loco and on rolling stock	Geared Jackshaft 3·7 motors only Air on loco and on rolling stock	Jackshaft- siderod 3·7 motor only Air on loco and on rolling stock
H.T. control (Brown-Boveri) E.P. 24 — 24 — Oil circulation	E.P. contactor E.P. — — — — Oil circulation	Manual sliding contact — 13 — 13 570kva. Self	Motor-driven sliding contact — 13 — 13 500kva. Forced air circu.
— Regenerative — 220v. A.C. 36v. D.C. 36v. 100AH.	— Rheostatic — 220v. A.C. 36v. D.C. 36v. 100AH.	Hand-operated oil-immersed None — 36v. D.C. 36v.	 None — 36v. D.C. 36v.
1 — — — — —	1 rotary 220v. 45 — — —	1 reciprocating — — — — —	1 reciprocating — — — — —
2 single 1000v. A.C.	2 single 1500v. A.C.	1 double 1000v. A.C.	1 double 1000v. A.C.

Country	SWITZERLAND	U.S.A.
Railway	FURKA-OBERALP	GRAND TRUNK
Gauge	3′ 3⅜″	4′ 8½″
Nominal Supply Voltage	11,000 v. 16⅔ cycles	3300 v. 25 cycles
Railway Type or Serial Nos.	HGe 4/4 31 etc.	9156
Makers of Mechanical Parts	S.L.M.	Baldwin
Makers of Electrical Parts	Oerlikon	Westinghouse
Type of Service	Mixed	Mixed
Axle Classification	$B_0 - B_0$	C_0
Year First in Service	1941	1927
Total Number in Service	5	1
Total Weight in Tons	45·8	63
Adhesive Weight in Tons	45·8	63
Weight of Mechanical Parts (tons)	—	34·7
Weight of Electrical Parts (tons)	—	28·3
Overall Length	46′ 4″	29′ 5″
Total Wheelbase	28′ 7½″	16′ 0″
Rigid Wheelbase	—	16′ 0″
Driving Wheel Diameter	37″	62″
Carrying Wheel Diameter	—	—
Traction Motors (No. and Type)	4 single-armature	3 single-armature
Motor Ventilation	1 blower	—
Total Motor Rated Horse Power: Continuous	—	636
Total Motor Rated Horse Power: One Hour	1240	816
Locomotive Continuous Rating: Speed in m.p.h.	—	19·4
Locomotive Continuous Rating: Tractive Effort (lbs.)	—	12,300
Locomotive One-Hour Rating: Speed in m.p.h.	—	16·2
Locomotive One-Hour Rating: Tractive Effort (lbs.)	25,500	18,900
Maximum Tractive Effort (lbs.)	—	34,000
Maximum Service Speed (m.p.h.)	34	26
System of Drive	Nose-sus. + rackdr.	Nose-suspension
Gear Ratio	5·65/5·77	5·31
Roller Bearings used on	Motors and axles	
Mechanical Brakes	Air on loco Vacuum on train	Air on loco and rolling stock
Tap Changer	—	—
Control Gear	—	—
Main Transformer Voltage Tappings	—	—
Intermediate Values obtained by	—	—
Total Running Points	—	—
Transformer Rating (exclud. Heating)	—	—
Transformer Cooler	—	—
Additional Circuit Breakers	—	None
Electric Braking	Rheostatic	None
Excitation for Braking	—	—
Low Tension Auxiliary Supply	—	—
Battery Details	—	—
Compressors: Number and Type	1 reciprocating	yes
Compressors: Motor Volts and Rating	—	—
Compressors: Capacity cu. ft./min.	—	—
Exhausters: Number and Type	1 reciprocating	—
Exhausters: Motor Volts and Ratng	—	—
Exhausters: Capacity cu. ft./min.	—	—
Pantographs—Number and Type	2 single	1 double
Train Heating System	—	None

U.S.A. New York New Haven and Hartford 4′ 8½″ 11,000v. 25 cycles and 600v. D.C. 0351 etc. G.E. G.E.	U.S.A. New York, New Haven and Hartford 4′ 8½″ 11,000v. 25 cycles 0361 etc. G.E. G.E.	U.S.A. New York, New Haven and Hartford 4′ 8½″ 11,000v. 25 cycles 0150 etc. Baldwin A.L.C.O. West'house, G.E.	U.S.A. New York, New Haven and Hartford 4′ 8½ 11,000v. 25 cycles 0218 etc. Baldwin Westinghouse
Express $2-C_0+C_0-2$ 1931 10	Passenger $2-C_0+C_0-2$ 1938 6	Freight $2-C_0+C_0-2$ 1943 10	Shunting B_0+B_0 1926 6
175·5 120·2 96·5 74·4	193 121 120 73	223 161 — —	81 81 — —
77′ 0″ 66′ 0″ 13′ 8″ 56″ 36″	77′ 0″ 66′ 0″ 13′ 8″ 56″ 36″	80′ 0″ 69′ 0″ 13′ 8″ 57″ 36″	39′ 1″ — 7′ 0″ 63″ —
6 twin-arm. 12-pole 2 motor-blower sets (A.C.) (D.C.) 2740 2610 3440 3140	6 twin-arm. 12-pole 2 motor-blower sets 3600 —	6 twin-armature 2 motor-blower sets each 25,000 c.f.m. 4860 at 65 m.p.h. 4780 at 39 m.p.h. —	4 single-armature Self 520 652
57 43·5 18,000 22,500 51·2 37·7 25,200 31,200 68,000 70	56·0 24,100 — — 68,500 93	39 46,000 — — 90,000 65	13·5 14,400 10·5 23,200 45,400 25
Quill and cup 3·81 motors only Air on loco and on rolling stock	Quill and cup 3·39 motors only Air on loco and on rolling stock	Quill and cup 4·94 motors only Air on loco and on rolling stock	Nose-suspension 5·94 — Air on loco and on rolling stock
E.P. contactor E.P. 12 None 12(4) — Air-blast	E.P. contactor E.P. 12 None 12 — —	E.P. contactor E.P. 22 — 66 — Forced air cooled	— — — — — — —
A.C.–oil & LT. h.-speed D.C.–High speed None — * 32v..	None None — — —	None None — — —	— None — — —
2 reciprocating — 97 — — —	2 — — — — —	2 A.C. series 100 — — —	1 — — — — —
2 single Oil-fired boiler	2 double Oil-fired boiler	2 double where required	2 double None

* 280v. A.C. or 600v. D.C., 32v. D.C.

Country	U.S.A.	U.S.A.
Railway	Pennsylvania	Pennsylvania
Gauge	4′ 8½″	4′ 8½″
Nominal Supply Voltage	11,000v. 25 cycles	11,000v. 25 cycles
Railway Type or Serial Nos.	01	01A
Makers of Mechanical Parts	Penn. RR.	Penn. RR.
Makers of Electrical Parts	Westinghouse	G.E.
Type of Service	Passenger	Passenger
Axle Classification	$2-B_0-2$	$2-B_0-2$
Year First in Service	1930	1930
Total Number in Service	2	2
Total Weight in Tons	137	138
Adhesive Weight in Tons	66	69·7
Weight of Mechanical Parts (tons)	89·4	90·6
Weight of Electrical Parts (tons)	47·6	47·5
Overall Length	52′ 8″	52′ 8″
Total Wheelbase	39′ 10″	39′ 10″
Rigid Wheelbase	10′ 0″	10′ 0″
Driving Wheel Diameter	72″	72″
Carrying Wheel Diameter	36″	36″
Traction Motors (No. and Type)	2 twin-armature	2 twin-armature
Motor Ventilation	Forced	Forced
Total Motor Rated Horse Power — Continuous	2000	2500
Total Motor Rated Horse Power — One Hour	—	—
Locomotive Continuous Rating — Speed in m.p.h.	56	63
Locomotive Continuous Rating — Tractive Effort (lbs.)	13,200	14,900
Locomotive One-Hour Rating — Speed in m.p.h.	—	—
Locomotive One-Hour Rating — Tractive Effort (lbs.)	—	—
Maximum Tractive Effort (lbs.)	33,500	33,500
Maximum Service Speed (m.p.h.)	90	90
System of Drive	Morch link	Quill and cup
Gear Ratio	2·93	2·86
Roller Bearings used on	Motors and axles	Motors and axles
Mechanical Brakes	Air on loco and on rolling stock	Air on loco and on rolling stock
Tap Changer	E.P. contactor	E.P. contactor
Control Gear	E.P.	E.P.
Main Transformer Voltage Tappings	9	9
Intermediate Values Obtained By	—	—
Total Running Points	20	18
Transformer Rating (exclud. Heating)	—	—
Transformer Cooler	Air-blast	Air-blast
Additional Circuit Breakers	None	None
Electric Braking	None	None
Excitation for Braking	—	—
Low Tension Auxiliary Supply	Single-phase and 32v. D.C.	Single-phase and 32v. D.C.
Battery Details	32v. 150AH.	32v. 150AH.
Compressors — Number and Type	1 reciprocating	1 reciprocating
Compressors — Motor Volts and Rating	35 h.p.	35 h.p.
Compressors — Capacity cu. ft./min.	150	150
Exhausters — Number and Type	—	—
Exhausters — Motor Volts and Rating	—	—
Exhausters — Capacity cu. ft./min.	—	—
Pantographs—Number and Type	2 double	2 double
Train Heating System	Oil-fired boiler	Oil-fired boiler

U.S.A. PENNSYLVANIA 4′ 8½″ 11,000v. 25 cycles 01B PENN. RR. Brown-Boveri	U.S.A. PENNSYLVANIA 4′ 8½″ 11,000v. 25 cycles 01C PENN RR. West'house, G.E.	U.S.A. PENNSYLVANIA 4′ 8½″ 11,000v. 25 cycles P5A PENN. RR., G.E., Baldwin West'house, G.E.	U.S.A. PENNSYLVANIA 4′ 8½″ 11,000v. 25 cycles No. 4999 Baldwin Westinghouse
Passenger $2-B_0-2$ 1931 2	Passenger $2-B_0-2$ 1931 2	Mixed Passenger $2-C_0-2$ 1933 1935 62 28	Passenger $2-D_0-2$ 1934 1
134·5 67·2 89·8 45·0	134 67 87·5 46·5	175 176 98·3 102·2 103·5 104·5 66 66	179 103 — —
52′ 8″ 39′ 10″ 10′ 0″ 72″ 36″	52′ 8″ 39′ 10″ 10′ 0″ 72″ 36″	62′ 8″ 49′ 10″ 20′ 0″ 72″ 36″	64′ 8″ — 23′ 0″ 62″ 36″
2 twin-armature Forced 2200 —	2 twin-armature Forced 2500 —	3 twin-armature Forced 3750 —	4 twin-armature Forced 5000 —
46 17,800 — — 33,500 90	63 14,900 — — 33,900 90	63 22,300 — — 56,250 90	100 18,750 — — 56,000 100
Buchli link inside wheels 2·33 Motors and axles Air on loco and on rolling stock	Quill and cup 2·93 Motors and axles Air on loco and on rolling stock	Quill and cup 2·93 Motors and axles Air on loco and on rolling stock	Quill and cup 2·74 Motors and axles Air on loco and on rolling stock
Sliding contact E.P. 18 None 18 — Air-blast	E.P. contactor E.P. 12 — 20 — Air-blast	E.P. contactor E.P. 11 — 21 4200 kva. Air-blast	E.P. contactor E.P. 11 — 21 — Air-blast
None None — Single-phase and 32v. D.C. 32v. 150AH.	None None — Single-phase and 32v. D.C. 32v. 300AH.	None None — Single-phase and 32v. D.C. 32v. 300AH.	None None — Single-phase and 32v. D.C. 32v. 300AH.
1 reciprocating 35 h.p. 150 — — —	1 reciprocating 35 h.p. 150 — — —	1 reciprocating 35 h.p. 150 — — —	1 reciprocating 35 h.p. 150 — — —
2 double Oil-fired boiler	2 double Oil-fired boiler	2 double Oil-fired boiler	2 double Oil-fired boiler

Country	U.S.A.	U.S.A.
Railway	Pennsylvania	Pennsylvania
Gauge	4′ 8½″	4′ 8½″
Nominal Supply Voltage	11,000v. 25 cycles	11,000v. 25 cycles
Railway Type or Serial Nos.	GG1 4800–4938	L6 5938–5940
Makers of Mechanical Parts	Penn. RR., G.E., Baldwin	Penn. RR., Lima
Makers of Electrical Parts	West'house, G.E.	West'house, G.E.
Type of Service	Express	Freight
Axle Classification	$2 - C_0 + C_0 - 2$	$1 - D_0 - 1$
Year First in Service	1934 1935 1937	1932
Total Number in Service	1 57 81	3
Total Weight in Tons	212 205 213	134
Adhesive Weight in Tons	135 134 135	107
Weight of Mechanical Parts (tons)	138·8 132 136	85·8
Weight of Electrical Parts (tons)	73·2 73 77	48·2
Overall Length	79′ 6″	51′ 10″
Total Wheelbase	69′ 0″	—
Rigid Wheelbase	13′ 8″	20′ 0″
Driving Wheel Diameter	57″	62″
Carrying Wheel Diameter	36″	36″
Traction Motors (No. and Type)	6 twin-arm 12 pole	4 single-armature
Motor Ventilation	2 motor-blow. sets each 25,000, c.f.m.	Forced
Total Motor Rated Horse Power — Continuous	4620	2500
Total Motor Rated Horse Power — One Hour	—	—
Locomotive Continuous Rating — Speed in m.p.h.	100 90 100	37·5
Locomotive Continuous Rating — Tractive Effort (lbs.)	17,300 19,140 17,300	25·000
Locomotive One-Hour Rating — Speed in m.p.h.	—	—
Locomotive One-Hour Rating — Tractive Effort (lbs.)	—	—
Maximum Tractive Effort (lbs.)	72,800	58,000
Maximum Service Speed (m.p.h.)	100 90 100	54
System of Drive	Quill and cup	Nose-suspension
Gear Ratio	3·21 3·59 3·21	4·3
Roller Bearings used on	Motors and axles	Motors and axles
Mechanical Brakes	Air on loco and	rolling stock
Tap Changer	E.P. contactor	E.P. contactor
Control Gear	E.P.	E.P.
Main Transformer Voltage Tappings	11	11
Intermediate Values Obtained By	Buck & bst. trans.	—
Total Running Points	66	21
Transformer Rating (exclud. Heating)	4800kva.	—
Transformer Cooler	Forced air circu.	Air-blast
Additional Circuit Breakers	None	None
Electric Braking	None	None
Excitation for Braking	—	—
Low Tension Auxiliary Supply	Sin-ph & 32v. D.C.	Sin-ph & 32v.D.C.
Battery Details	32v. 300AH.	32v. 300AH.
Compressors — Number and Type	1 reciprocating	1 reciprocating
Compressors — Motor Volts and Rating	35 h.p.	35 h.p.
Compressors — Capacity cu. ft./min.	150	150
Exhausters — Number and Type	—	—
Exhausters — Motor Volts and Rating	—	—
Exhausters — Capacity cu. ft./min.	—	—
Pantographs—Number and Type	2 double	2 double
Train Heating System	Oil-fired boiler	None

U.S.A. PENNSYLVANIA 4′ 8½″ 11,000v. 25 cycles Converted P5A 4702 PENN. RR. G.E.	U.S.A. PENNSYLVANIA 4′ 8½″ 11,000v. 25 cycles 5800 PENN. RR. Westinghouse	U.S.A. PENN.-LONG ISLAND 4′ 8½″ 11,000v. 25 cycles { PENN. 3900–1, 3910-21, 5684-97 L.I. 324–337 } PENN. RR. Westinghouse	
Freight $B_0+C_0+B_0$ 1938 1	Freight $2-B_0+B_0-2$ 1938 1	Shunting C_0 1926 28 14	
198·5 198·5 95·5 103	201 128 128·5 72·5	70 70 — —	
62′ 8″ 49′ 10″ 20′ 0″ 72″ 36″ —	72′ 6″ — 14′ 11″ 62″ 36″	31′ 6″ 12′ 8″ 12′ 8″ 62″ —	
{ 3 twin-armature 4 single-armature } Forced 5350 —	4 twin-armature Forced 5000 —	3 single-armature — 570 730	
49·0 41,000 — — 107,000 70	49 38,300 — — 69,500 70	15·9 13,500 13·4 22,100 39,200 25 40	
Quill & cup Nose-susp. 3·72 2·94 Motors and axles Air	Quill and cup 3·96 Motors and axles on loco and roll-	Nose-suspension 5·43 4·63 — ing stock	
E.P. contactor E.P. 11 — 21 — Air-blast	E.P. contactor E.P. 11 — — 4800kva. Forced air circu.	E.P. contactor E.P. — — — — —	
None None — Sin-ph & 32v. D.C. 32v. 300AH.	None None — Sin-ph & 32v. D.C. 32v. 300AH.	None None — — —	
1 reciprocating 35 h.p. 150 — — —	1 reciprocating 35 h.p. 150 — — —	1 — — — — —	
2 double None	1 double None	1 double None	

Country	AUSTRIA	FRANCE
Railway	FEDERAL	S.N.C.F. (STATE)
Gauge	4′ 8½″	4′ 8½″
Nominal Supply Voltage	15,000v. 16⅔ cycles	1500v. D.C.
Railway Type or Serial Nos.	1082.01	CC 1001 etc.
Makers of Mechanical Parts	W.L.	Batignolles
Makers of Electrical Parts	S.S.W.	Oerlikon
Type of Service	Freight	Shunting
Axle Classification	1 – E – 1(1)	C – C
Year First in Service	1930	1938
Total Number in Service	1	12
Total Weight in Tons	117	89
Adhesive Weight in Tons	85·6	89
Weight of Mechanical Parts (tons)	59	—
Weight of Electrical Parts (tons)	58	—
Overall Length	51′ 4″	56′ 5″
Total Wheelbase	40′ 7″	40′ 4½″
Rigid Wheelbase	15′ 7″	—
Driving Wheel Diameter	53¼″	55″
Carrying Wheel Diameter	40¾″	—
Traction Motors (No. and Type)	3 direct current	4 dir. cur. 375v.
Motor Ventilation	Forced	Forced
Supply to Traction Motors	Direct current	D.C. to all 4 motors connected in series
Total Motor Rated Horse Power — Continuous	1580	480
Total Motor Rated Horse Power — One Hour	1775	616
Locomotive Continuous Rating — Speed in m.p.h.	23·3	7·27
Locomotive Continuous Rating — Tractive Effort (lbs.)	24,450	24,700
Locomotive One-Hour Rating — Speed in m.p.h.	22·7	6·39
Locomotive One-Hour Rating — Tractive Effort (lbs.)	28,200	34,400
Maximum Tractive Effort (lbs.)	45,200	44,150
Maximum Service Speed (m.p.h.)	37	31
System of Drive	Nose-sus. + coup. rods	Nose-sus. + coup. rods
Gear Ratio	6·14	7·14
Roller Bearings used on	Motors only	—
Mechanical Brakes	Air-loco Air or vac. stock	Air on locos and stock
Type of Convertor	Phase convert. feeding two rotary convertors on one shaft	1500v. D.C. motor driving 0–1500v. D.C. generator
Voltage Regn. of Convertor for Speed Control	by moving brushgear	by field regulation
Control Gear	E.P. contactor	E.P. contactor
System of Speed Adjustment	Variable voltage	Variable voltage
Total Running Points	—	—
Transformer Rating (excluding heating)	1600kva.	None
Transformer Cooler	Corrugations on tank Forced air circulation	—
Additional Circuit Breakers	Oil	—
Electric Braking	Regenerative	Regenerative
Excitation for Braking	Excitor on	convertor.
Low Tension Auxiliary Supply	24v. A.C. 24v. D.C.	72v.
Battery Details	24v.	72v. 72AH. Nick-Cad
Compressors — Number and Type	1 rotary	1
Compressors — Motor Volts and Rating	—	1350v.
Compressors — Capacity cu. ft./min.	82·5	43·5
Exhausters — Number and Type	1	—
Exhausters — Motor Volts and Rating	—	—
Exhausters — Capacity cu. ft./min.	95	—
Pantographs—Number and Type	2 single	1 single
Train Heating System	1000v. A.C.	None

GREAT BRITAIN	HUNGARY	U.S.A.	U.S.A.
SOUTHERN	STATE	GREAT NORTHERN	GREAT NORTHERN
4′ 8½″	4′ 8½″	4′ 8½″	4′ 8½″
660v. D.C.	15,000v. 50 cycles	11,000v. 25 cycles	11,000v. 25 cycles
CC1 CC2	40001 etc.	5000 etc.	5014 etc.
Southern Rly.	R.H.S.E.W.	Baldwin	A.L.C.O.
E.E.Co.	Ganz. M.V.	Westinghouse	G.E.
Mixed	Mixed Freight	Mixed	Mixed
$C_0 - C_0$	$1 - D - 1$ E	$1 - D_0 - 1$	$1 - C_0 + C_0 - 1$
1941	1933 1933	1927 1928	1930
2	24 2	4 6	8
99·7	92·5 92·5	159·5 165·7	240·0
99·7	65·7 92·5	122·5 127·2	190·0
—	—	82·7 86·7	112·5
—	—	76·7 79·0	126·5
56′ 9″	44′ 9″ 44′ 1″	47′ 2″	73′ 9″
43′ 6″	25′ 9″ —	31′ 5″	58′ 8″
16′ 0″	—	16′ 9″	15′ 4″
42″	65½″ 45½″	56″	55″
—	41″ —	36″	36″
6 single-arm. D.C.	1 induction	4 direct current	6 direct current
Forced	Forced	*	Forced
Direct current	3, 4 or 6-phase	600v. D.C.	750/1500v. D.C.
—	2200	1880	3000
1710	2500	2215	3300
—	62·1 42·6	15·5	18·7
—	12,900	44,250	60,000
—	62·0 —	14·4	18·0
—	14,750	56,250	67,200
45,000	—	69,250	124,000
75	62 43·6	37 45	45
Nose-suspension	Kando rod	Nose-suspension	Nose-suspension
—	—	5·05	3·90
Motors only	None	Motors of 1 unit	None
Air-loco	Air on loco and	Air on loco and	Air on loco and
Vacuum on stock	on rolling stock	on rolling stock	on rolling stock
Two D.C. M-G sets with flywheels on shafts	Phase convertor	1770kva. syn. motor driving 1500kw. D.C. genr. and 2 exciters	3100kva. syn. motor dr. 2 1250kw. 750v. D.C. gen. and 2 exciters
Field regulation	None	Adjust. of genr. field	Adjust. of gen. fields
E.P. & E.M. contactor	E.P. camshaft	—	E.P. camshaft
Variable voltage of motor-booster sets	Pole changing on motor Interm. val. by rot. resis.	Variable voltage	Variable voltage
26	4	29	—
None	None	2000kva.	—
—	—	Air-blast	Air-blast
—	Oil	—	—
None	Inher. regeneration	Regenerative	Regenerative
—	—	Excit. on convert.	Excit. on convert.
—	A.C.	300v 3ph A.C. 125v D.C.	L.T.A.C. & 65v. D.C.
Fitted	—	112v. 230AH.	—
2	2 reciprocating	1 reciprocating	2 reciprocating
660v.	—	35 h.p.	—
25	40	150	100
2	—	—	—
—	—	—	—
90	—	—	—
1 double	2 single	2 double	2 double
Elec.-heated boiler	Single-phase	None	None

* Two 10 h.p. 3-phase A.C. motor-blower sets.

Country	U.S.A.	U.S.A.
Railway	N.Y. New Haven and Hartford	VIRGINIAN
Gauge	4′ 8½″	4′ 8½″
Nominal Supply Voltage	11,000v. 25 cycles	11,000v. 25 cycles
Railway Type or Serial Nos.	0112 etc.	EL1
Makers of Mechanical Parts	A.L.C.O.	A.L.C.O.
Makers of Electrical Parts	G.E.	Westinghouse
Type of Service	Freight	Freight
Axle Classification	$1-B_0+B_0-1$	$1-B-B-1$
Year First in Service	1926	1925
Total Number in Service	5	36
		end un. mid un. dbl cab
Total Weight in Tons	125	191 190 192
Adhesive Weight in Tons	98·2	137·5 136·5 138
Weight of Mechanical Parts (tons)	—	120·5 119·5 121·5
Weight of Electrical Parts (tons)	—	70·5 70·5 70·5
Overall Length	38′ 3″	53′ 0″
Total Wheelbase	31′ 0″	37′ 6″
Rigid Wheelbase	8′ 3″	16′ 6″
Driving Wheel Diameter	42″	63″
Carrying Wheel Diameter	36″	—
Traction Motors (No. and Type)	4 direct current	2 induction
Motor Ventilation	Forced	1 blower
Supply to Traction Motors	600v. D.C.	1150v.
		(8-pole) (4-pole)
Total Motor Rated Horse Power — Continuous	1150	1700 2000
Total Motor Rated Horse Power — One Hour	1360	2030 2375
Locomotive Continuous Rating — Speed in m.p.h.	24·6	14·2 28·4
Locomotive Continuous Rating — Tractive Effort (lbs.)	17,100	45,000 26,250
Locomotive One-Hour Rating — Speed in m.p.h.	20·4	14·1 28·3
Locomotive One-Hour Rating — Tractive Effort (lbs.)	24,800	54,000 31,500
Maximum Tractive Effort (lbs.)	56,200	92,500
Maximum Service Speed (m.p.h.)	42	30
System of Drive	Nose-suspension	Jackshaft & coup. rod
Gear Ratio	4·24	4·76
Roller Bearings used on	Motors only	None
Mechanical Brakes	Air on locos and	on rolling stock
Type of Convertor	1000kw. M.G. set	Phase convertor
Voltage Regn. of Convertor for Speed Control	Adjt. of gen. field	None
Control Gear	E.P. camshaft	—
System of Speed Adjustment	Variable voltage	Pole-chang. on motors
Total Running Points	—	2 (inter. by rotor resis.)
Transformer Rating (exclud. Heating)	1312 kva.	2350 kva.
Transformer Cooler	Air-blast	Forced air circu.
Additional Circuit Breakers	—	Oil
Electric Braking	None	Inherent regen.
Excitation for Braking	—	None required
Low Tension Auxiliary Supply	32v. D.C. from aux. conv. set	300v. 3ph. & 32v. D.C. 900w. M.G. set
Battery Details	32v.	32v. 75AH.
Compressors — Number and Type	2 reciprocating	1 reciprocating
Compressors — Motor Volts and Rating	—	45 h.p.
Compressors — Capacity cu. ft./min.	100	150
Exhausters — Number and Type	—	—
Exhausters — Motor Volts and Rating	—	—
Exhausters — Capacity cu. ft./min.	—	—
Pantographs—Number and Type	2 single	1 double
Train Heating System	None	None

Country	U.S.A.	U.S.A.
Railway	New York Central	Delaware, Lackawanna & Western
Gauge	4′ 8½″	4′ 8½″
Serial Nos.	526–560	3501–2
Makers of Engine	Ingersoll-Rand	Ingersoll-Rand
Makers of Mechanical Parts	do. G.E.	do. G.E.
Makers of Electrical Parts	G.E.	G.E.
Type of Service	Shunting and local freight	
Axle Classification	$B_0 - B_0$	$B_0 - B_0$
Year First in Service	1930	1930
Total Number in Service	35	2
Total Weight in Tons	115	112
Adhesive Weight in Tons	115	112
Weight of Mechanical Parts (tons)	55·5	57·3
Weight of Electrical Parts (tons)	59·5	54·7
Overall Length	47′ 0″	48′ 0″
Total Wheelbase	34′ 1″	34′ 7″
Rigid Wheelbase	8′ 3″	8′ 3″
Driving Wheel Diameter	44″	43″
Carrying Wheel Diameter	None	None
Traction Motors (No. and Type)	4 single-armature	4 single-armature
Motor Ventilation Details	Forced—2 motor-blower sets	
Armature Voltage	600	1500
†Total Motor Rated Horse Power — Continuous	1300	1450
†Total Motor Rated Horse Power — One Hour	1665	1600
†Locomotive Continuous Rating — Speed in m.p.h.	19·8	24·5
†Locomotive Continuous Rating — Tractive Effort (lbs.)	24,600	22,200
†Locomotive One-Hour Rating — Speed in m.p.h.	18·3	23·8
†Locomotive One-Hour Rating — Tractive Effort (lbs.)	34,100	25,200
Maximum Tractive Effort (lbs.)	64,250	64,250
Maximum Service Speed (m.p.h.)	40	40
System of Drive	Nose-suspension	Nose-suspension
Gear Ratio	4·235	4·235
Roller Bearings used on	None	None
Mechanical Brakes	Air on locos and stock	
Control System	E.P. contactor	E.P. contactor
Armature Combinations (external supply) — Series	4 2 —	4 2
Armature Combinations (external supply) — Parallel	— 2 4	— 2
Armature Combinations (internal supply) — Series	4 2 —	4 2 —
Armature Combinations (internal supply) — Parallel	— 2 4	— 2 4
Values of Reduced Field	None	None
External Supply	600v. D.C. (third rail)	3000v. D.C. (overhead)
Battery	240 cell 650 AH.	360 cell 340 AH.
Battery Voltage	464	712
Engine Description	1 six-cylinder four-stroke	1 six-cylinder four-stroke
Engine Speed (r.p.m.)	550/575	550/575
Generator Rating (kw.)	200	200
Auxiliary Supply	from exter. supply or battery	from battery
Compressors — Number and Type	1 motor driven	1 motor driven
Compressors — Motor Volts	600	750
Compressors — Capacity	—	—

* A "three-power" locomotive is one which can operate from either
(*a*) An external supply.
(*b*) A battery carried on the locomotive.
(*c*) An engine-driven generator carried on the locomotive and floating in parallel with the battery.

† On external supply.

Country	ALGERIA	ARGENTINA
Railway	ALGERIAN	Buenos Ayres G.S.
Gauge	3′ 3⅜″	5′ 6″
Railway Type or Number	6XADE 1 and 2	—
Makers of Diesel Engine	C.C.M. Sulzer	Sulzer
Makers of Mechanical Parts	Mar.-Homécourt	A.W.
Makers of Electrical Parts	Jeumont	Br.-Bov., E.E.Co.
Type of Service	Freight	Passenger
Axle Classification	$C_0 - C_0$	$1A - B_0 + B_0 - A1$
Year First in Service	1938	1933
Total Number in Service	2	1
Total Weight in Tons	64	148·5
Adhesive Weight in Tons	64	112
Overall Length	45′ 11½″	71′ 6″
Total Wheelbase	34′ 1½″	65′ 4″
Rigid Wheelbase	—	8′ 5″ and 9′ 0″
Driving Wheel Diameter	39⅜″	42″
Carrying Wheel Diameter	—	37½″
No. of Engines, Type and Description	One 6-cylinder four-stroke	Two 8-cylinder four-stroke
Cylinders Bore × Stroke (ins.)	9·85 × 12·6	13·4 × 15·8
Supercharger	Rateau turbo-blow	None
B.H.P. per Engine	735	850
Generator Rating: Continuous	450v 900A 405kw	570kw. each
Generator Rating: One Hour	405v 1120A 453kw	—
Traction Motors (No. and Type)	6 single-armature	6 single-armature
Motor Ventilation	Self	Self
Armature Voltage	450	750
Total Motor Rating: Continuous	486 h.p.	1380 h.p.
Total Motor Rating: One Hour	540 h.p.	1860 h.p.
Maximum Locomotive Horse Power	735	1700
Locomotive Continuous Rating: Speed in m.p.h.	18·6	33
Locomotive Continuous Rating: Tractive Effort (lbs.)	8,815	15,000
Locomotive One-Hour Rating: Speed in m.p.h.	16·4	20
Locomotive One-Hour Rating: Tractive Effort (lbs.)	12,560	24,500
Maximum Tractive Effort (lbs.)	24,250	35,000
Maximum Service Speed (m.p.h.)	37·2	70
Type of Control	Jeumont axle-dr. exctr. with Br.-Bov. field reg.	Auto-regulator
Motor Combinations: Series	—	— per genr.
Motor Combinations: Parallel	6	3 per genr.
Motor Field Control	None	None
Running Notches	8	3
Engine Speeds (r.p.m.)	460 760 850	550 max.
System of Drive	Nose-suspension	Nose-suspension
Gear Ratio	5·27	3·89
Roller Bearings fitted on	Motors only	Motors and axles
Mechanical Brakes	Air on loco and stk	Vac. on loco & stk.
Auxiliary Engines	None	None
Auxiliary Supply	170v.	120v.
Exciter Output	2x50v 45A 2·25 kw.	130v. 62·5kw.
Battery	90 cell Ni-Cad.	Ni-Cad.
Compressors: No. and Type	1	1
Compressors: Driven by	Motor	110v. 2·5 h.p. motor
Compressors: Capacity cu. ft./min.	35·3	—
Exhausters: No. and Type	—	1 rotary
Exhausters: Driven by	—	110v. 12·75 h.p. motor
Exhausters: Capacity cu. ft./min.	—	—
Train Heating	None	None

ARGENTINA Buenos Ayres G.S. 5′ 6″ — A.W.—Sulzer A.W. L.S. and E., C.P.	ARGENTINA Buenos Ayres, G.S. 5′ 6″ — Harland & Wolff Harland & Wolff L.S. and E., Br. Bov	ARGENTINA Buenos Ayres Hbr 5′ 6″ — M.A.N. Esslingen Brown-Boveri	ARGENTINA ROSARIO 5′ 6″ — Sulzer Henschel Oerlikon
Mixed traffic $1 - C_0 - 1$ 1937 1	Mixed traffic $1 - D_0 - 1$ 1937 2	Shunting $B_0 - B_0$ 1930 3	Shunting $B_0 - B_0$ 1931 3
81 52·3 38′ 6″ 30′ 0″ — 48″ 36″	104·7 72·0 46′ 0″ 37′ 0″ — 55½″ 41″	58 58 32′ 9½″ 24′ 3½″ 7′ 2½″ 39⅜″ —	57·5 57·5 36′ 0″ 25′ 11″ 8′ 2″ 36″ —
One 8-cylinder four-stroke 11″ × 15″ None 800 — —	Two 8-cylinder two-stroke 7·1 × 11·8 Scavenging blows. 450 * 285v. 1000A. 285kw 255v. 1220A. 311kw	One 6-cylinder four-stroke 8·7 × 12·6 None 300 220kw. —	One 6-cylinder four-stroke — None 330 — —
3 single-armature Forced 800 660 h.p. 990 h.p.	4 single-armature Forced 550 764 h.p. 833 h.p.	4 single-armature Self — — 380 h.p.	4 single-armature Self — — —
880 34 7,200 18 13,800 28,500 70	900 21 11,500 17 15,500 39,500 62	300 — — 4·35 21,200 39,600 28	330 — — 5·4 16,950 30,800 28
Auto-regulator — 3 — 5 700 max.	Auto-regulator — } per 2 } generator — 10 800 max.	Ward-Leonard 4 2 — 2 — 1 shunt — 700 max.	Ward-Leonard — — — — 700 max.
Nose-suspension 3·58 None Vac. on loco. & stk.	Nose-suspension 4·5 Motors and axles Vac. on loco & stk.	Nose-suspension — Motors only Air on loco	Nose-suspension — — Air on loco & stk.
One 6-cyl. 80 h.p. 160v. 160v. 50kw. Ni-Cad.	None 120v. 135v. 34kw. Ni-Cad.	None — 22kw. —	None — — —
1 120v. 0·75 h.p. mot. — 1 rotary 160v. 8 h.p motor —	1 120v. 2·25 h.p. mot. — 1 rotary 110v. 8 h.p. motor —	1 Motor — — — —	1 Motor — — — —
None	None	None	None

* Per generator.

Country	AUSTRALIA	BRAZIL
Railway	SOUTH AUSTRALIAN	EASTERN
Gauge	5′ 3″	3′ 3⅜″
Railway Type or Number		
Makers of Diesel Engine	E.E.Co.	E.E.Co.
Makers of Mechanical Parts	S. Australian Rlys	E.E.Co., H.L.
Makers of Electrical Parts	E.E.Co.	E.E.Co.
Type of Service	Freight & Shunt.	Mixed traffic
Axle Classification	$B_0 - B_0$	1 – BB – 1
Year First in Service	1946	1939
Total Number in Service	2	3
Total Weight in Tons	48	54·5
Adhesive Weight in Tons	48	38·5
Overall Length	36′ 3″	32′ 10″
Total Wheelbase	—	24′ 9″
Rigid Wheelbase	—	12′ 9″
Driving Wheel Diameter	36″	42″
Carrying Wheel Diameter	—	28½″
No. of Engines, Type and Description	One 6-cylinder four-stroke	One 8-cylinder four-stroke
Cylinders Bore × Stroke (ins.)	10 × 12	10 × 12
Supercharger	None	None
B.H.P. per Engine	350	470
Generator Rating: Continuous	190kw.	250kw.
Generator Rating: One Hour	—	—
Traction Motors (No. and Type)	4 single-armature	2 single-armature
Motor Ventilation	Motor-blower set	Belt-dr. blower
Armature Voltage	300	500
Total Motor Rating: Continuous	—	320 h.p.
Total Motor Rating: One Hour	—	440 h.p.
Maximum Locomotive Horse Power	350	450
Locomotive Continuous Rating: Speed in m.p.h.	16·4	29·0
Locomotive Continuous Rating: Tractive Effort(lbs.)	4800	4400
Locomotive One-Hour Rating: Speed in m.p.h.	15·3	24·8
Locomotive One-Hour Rating: Tractive Effort(lbs.)	5400	5100
Maximum Tractive Effort (lbs.)	25,000	19,800
Maximum Service Speed (m.p.h.)	45	50
Type of Control	Twin-field-self + battery auto-trans.	Torque control
Motor Combinations: Series	4 2	2 –
Motor Combinations: Parallel	– 2	– 2
Motor Field Control	–, 1 step shunt	–, 1 step shunt
Running Notches	—	7
Engine Speeds (r.p.m.)	340 to 680	350, 480, 560, 680
System of Drive	Nose-suspension	Nose-sus. & coup. rods
Gear Ratio	4·33	4·06
Roller Bearings fitted on	Motors only	Motors only
Mechanical Brakes	Air on loco and	on rolling stock
Auxiliary Engines	None	None
Auxiliary Supply	85v.	85v.
Exciter Output	85v. 15·3kw.	100v. 11kw.
Battery	40 c. 142 AH lead-acid	40 c. 224AH lead-acid
Compressors: No. and Type	2 reciprocating	2 reciprocating
Compressors: Driven by	85v. motors	80v. motors
Compressors: Capacity cu. ft./min.	25	25
Exhausters: No. and Type	—	—
Exhausters: Driven by	—	—
Exhausters: Capacity cu. ft./min.	—	—
Train Heating	None	None

Canada Canadian National 4′ 8½″ 7750 Ingersoll-Rand C.N.R. Canadian G.E.Co.	Canada Canadian Pacific 4′ 8½″ Harland & Wolff National Steel L. S. and E.	Denmark State 4′ 8½″ Frichs Frichs Titan	Denmark Private 4′ 8½″ Frichs Frichs Titan
Shunting $B_0 - B_0$ 1932 1	Shunting $B_0 - B_0$ 1937 1	Passenger $2 - D_0 - 2$ 1931 2	Mixed traffic $1 - C_0 - 1$ 1934–8 15
106 106 44′ 0″ 30′ 6″ 8′ 0″ 43″ —	109·5 109·5 43′ 3½″ 30′ 0″ 8′ 0″ 45″ —	102·8 51·7 51′ 10″ 40′ 1″ 15′ 1″ 55″ 37″	52 33·5 28′ 7″ 21′ 8″ — 49½″ 37″
Two 6-cylinder four-stroke 10 × 12 None 300 — —	One 6-cylinder two-stroke 8·65 × 14·6 Scavenging blower 550/600 290v. 1340A. 388kw 285v. 1720A 490kw	Two 6-cylinder four-stroke 11·2 × 13·0 None 450/500 295 kw. each 350 kw. each	One 6-cylinder four-stroke 10·24 × 13·0 None 410/450 275kw. 275kw.
4 single-armature Motor-blower set — — 772 h.p.	4 single-armature Motor-blower set* 500 520 h.p. 655 h.p.	4 single-armature Self 550 — 830 h.p.	3 single-armature Self 650 330 h.p. 450 h.p.
600 — — — — 63,600 40	600 5·3 28,000 3·4 38,000 60,000 30	760 28 9920 24 14,340 37,550 70	340 h.p. 31 3970 21 5950 11,050 53
G.E.C. Lemp. 4 2 { Auto- — 2 { trans. None — 550	Ward-Leonard + axle-driv. exciter — 4 1 tapping 4 300, 450, 600	Ward-Leonard — 4 None 13 350, 500, 600	Ward-Leonard — 3 None 12 350, 500, 650
Nose-suspension — None Air on locomotive	Nose-suspension 4·05 Motors only and on rolling stock	Nose-suspension 5·66 Motors and axles Air loco. vac.-stock	Nose-suspension 5·47 Motors and axles Vac.—loco & stk.
None 125v. 125v. — 56 cell 100AH lead-acid	None 120v. 54kw. 15 kw. axle driven 56 cell 450 AH. lead-acid	None 65/90v. 15kw. each 500AH.	None 110/150v. 27kw. 193AH.
1 Motor — — — —	2 Motors — — — —	1 8 h.p. motor — 1 22 h.p. motor —	— — — 1 110/150v 3 h.p. mr. 62
None	None	Oil-fired boiler	None

* 9500 c.f.m. to motors and generators

Country	DENMARK	FRANCE
Railway	PRIVATE	Soc. Nat. des Che. de fer (state)
Gauge	4′ 8½″	4′ 8½″
Railway Type or Number	—	4AMD1
Makers of Diesel Engine	Frichs	M.A.N.
Makers of Mechanical Parts	Frichs	Cie E.M.
Makers of Electrical Parts	Titan	Cie E.M.
Type of Service	Mixed traffic	Shunting
Axle Classification	1 – C_0 – 1	A1A – A1A
Year First in Service	1935	1932
Total Number in Service	1	1
Total Weight in Tons	48·0	83·0
Adhesive Weight in Tons	33·0	70·4
Overall Length	27′ 3″	42′ 4″
Total Wheelbase	21′ 8″	28′ 3″
Rigid Wheelbase	—	—
Driving Wheel Diameter	49½″	45¾″
Carrying Wheel Diameter	37″	32″
No. of Engines, Type and Description	One 6-cylinder four-stroke	One 6-cylinder four stroke
Cylinders Bore × Stroke (ins.)	11·22 × 13·0	11·0 × 15·0
Supercharger	None	None
B.H.P. per Engine	500/550	600
Generator Rating: Continuous	310kw.	270v. 345kw.
Generator Rating: One Hour	300kw.	220v. 340kw.
Traction Motors (No. and Type)	3 single-armature	4 single-armature
Motor Ventilation	Self	Forced
Armature Voltage	650	600
Total Motor Rating: Continuous	—	392 h.p.
Total Motor Rating: One Hour	615 h.p.	463 h.p.
Maximum Locomotive Horse Power	433	600
Locomotive Continuous Rating: Speed in m.p.h.	28	6·4
Locomotive Continuous Rating: Tractive Effort (lbs.)	5290	22,900
Locomotive One-Hour Rating: Speed in m.p.h.	15	4·23
Locomotive One-Hour Rating: Tractive Effort (lbs.)	9580	29,750
Maximum Tractive Effort (lbs.)	16,550	44,100
Maximum Service Speed (m.p.h.)	50	34
Type of Control	Ward-Leonard	Auto-regulator
Motor Combinations: Series	—	—
Motor Combinations: Parallel	2	4
Motor Field Control	None	None
Running Notches	13	16
Engine Speeds (r.p.m.)	350, 500, 650	300, 450, 700
System of Drive	Nose-suspension	Nose-suspension
Gear Ratio	5·36	6·06
Roller Bearings fitted on	Motors and axles	None
Mechanical Brakes	Air on loco & stk.	Air on locos & stk.
Auxiliary Engines	None	None
Auxiliary Supply	65/90v.	150v.
Exciter Output	35kw.	150v. 65kw.
Battery	300AH.	90 c. 420AH. Ni-Cad.
Compressors: No. and Type	3	2
Compressors: Driven by	6 h.p. motors	motor
Compressors: Capacity cu. ft./min.	25	71
Exhausters: No. and Type	—	—
Exhausters: Driven by	—	—
Exhausters: Capacity cu. ft./min.	—	—
Train Heating	None	None

FRANCE	FRANCE	FRANCE	FRANCE
Soc. Nat. des Che.	Soc. Nat. des Che.	Soc. Nat. des Che.	Soc. Nat. des Che.
de fer (state)	de fer (state)	de fer (state)	de fer (state)
4′ 8½″	4′ 8½″	4′ 8½″	4′ 8½″
D1	4CMD1	4BMD1	141AMD1
C.C.M., Sulzer	B. and W.	C.C.M.—Sulzer	M.A.N.
Cie. E.M.	Schneider	Mar.-Homécourt	S.C.E.F.
Cie E.M., Br.-Bov.	Schnr.-West'house	Alsthom	Alsthom
Mixed traffic	Shunting	Shunting	Shunting
$1-D_0-1$	B_0-B_0	B_0-1-B_0	$1-D_0-1$
1933	1933	1933	1933
1	1	1	1
87·0	70·8	82·5	93·0
65·4	70·8	70·0	70·5
46′ 10″	35′ 7″	44′ 3½″	45′ 10″
36′ 1″	24′ 11″	30′ 2″	35′ 7″
—	—	—	—
45¼″	43¼″	48″	49½″
31½″	—	34″	34″
One 8-cylinder	One 6-cylinder	One 8-cylinder	One 6-cylinder
four-stroke	two-stroke	four-stroke	four-stroke
11·0 × 13·4	9·83 × 13·4	11·0 × 13·4	11 × 15
None	Scavenging blower	None	None
800	600	600	600
450v. 475kw.	640v. 320kw.	500v. 350kw.	880/1320v. 343kw.
350v. 475kw.	650v. 400kw.	325v. 325kw.	660v. 343kw.
4 single-armature	4 single-armature	4 single-armature	4 single-armature
Forced	Self	2. 10 h.p. mot.-blr. sets	15 h.p. blower set
—	600	940	1400
—	413 h.p.	628 h.p.	—
542 h.p.	633 h.p.	890 h.p.	456 h.p.
800	600	600	600
13·9	16	14·6	4·35
13,200	15,400	11,000	29,250
9·95	9·2	4·35	2·95
17,600	20,850	30,870	43,150
35,300	46,300	39,700	35,300
37	40·5	37	43·5
Servo-field regu.	Manual—overld. indic.	Manual	Alsthom-Royce govr.
—	—	—	2 —
4	4	4	2 4
None	None	None	None
16	20	19	18
320, 510, 700	550 max.	500, 600, 700	450, 600, 700
Nose-suspension	Nose-suspension	Nose-suspension	Nose-suspension
5·6	4·31	6·23	6·07
None	None	—	—
Air	on locomotives	and on rolling	stock
None	None	None	None
150v.	170v.	150v.	150v.
120v. 72kw.	170v. 25kw.	150v. 66·5kw.	155v. 31kw.
420AH. Ni-Cad.	60 cell 550AH. lead-acid	92 c. 420AH. lead-acid	92 c. 420AH. Ni-Cad.
2	1 1	2	2
10 h.p. motors	engine motor	Motor	Motor
36	— —	71	71
—	—	—	—
—	—	—	—
—	—	—	—
None	None	None	None

Country	FRANCE	FRANCE
Railway	S.N.C.F.*	S.N.C.F.*
Gauge	4′ 8½″	4′ 8½″
Railway Type or Number	4DMD1 etc.	262BD1
Makers of Diesel Engine	C.C.M.—Sulzer	C.C.M.—Sulzer
Makers of Mechanical Parts	Mar.-Homécourt	Mar.-Homécourt
Makers of Electrical Parts	Jeumont	Jeumont
Type of Service	Shunting	Express
Axle Classification	$B_0 - B_0$	$2-C_0-2+2-C_0-2$
Year First in Service	1938	1937
Total Number in Service	3	1
Total Weight in Tons	66·7	227·5
Adhesive Weight in Tons	66·7	103·5
Overall Length	40′ 0″	108′ 4″
Total Wheelbase	29′ 2½″	95′ 10″
Rigid Wheelbase	—	15′ 10″
Driving Wheel Diameter	44″	59″
Carrying Wheel Diameter	—	39⅜″
No. of Engines, Type and Description	One 6-cylinder four-stroke	Two 12-cyl. twin bank engines
Cylinders Bore × Stroke (ins.)	9·83 × 12·6	12·2 × 15·4
Supercharger	Rateau turbo-ch.	Rateau turbo-ch.
B.H.P. per Engine	550	1900/2200
Generator Rating — Continuous	355v. 355kw.	790v. 1220kw. each
Generator Rating — One Hour	315v. 352kw.	790v. 1420kw. each
Traction Motors (No. and Type)	4 single-armature	6 single-armature
Motor Ventilation	2.2 h.p. mot.-blw. sets	2. 19 h.p. mot-blw. sets
Armature Voltage	355	790
Total Motor Rating — Continuous	355v. 478 h.p.	3270 h.p.
Total Motor Rating — One Hour	315. 472 h.p.	3810 h.p.
Maximum Locomotive Horse Power	635	4400
Locomotive Continuous Rating — Speed in m.p.h.	9·5	71(1)
Locomotive Continuous Rating — Tractive Effort (lbs.)	15,600	19,400
Locomotive One-Hour Rating — Speed in m.p.h.	8·1	54·8
Locomotive One-Hour Rating — Tractive Effort (lbs.)	18,170	20,000
Maximum Tractive Effort (lbs.)	37,500	52,900
Maximum Service Speed (m.p.h.)	31	81
Type of Control	Manual with overload indictor	Servo-field regu.& axle-dr. exciters
Motor Combinations — Series	—	— per generator
Motor Combinations — Parallel	4	3 per generator
Motor Field Control	None	Shunts (40%)
Running Notches	9	15
Engine Speeds (r.p.m.)	460 min. 815 max.	400, 500, 600, 700
System of Drive	Nose-suspension	Quill and cup
Gear Ratio	3·65	2·81
Roller Bearings fitted on	Motors only	Motors only
Mechanical Brakes	Air on loco and on rolling stock	Air on loco and on rolling stock
Auxiliary Engines	None	None
Auxiliary Supply	170v.	120/150v.
Exciter Output	170v. 40kw.	2. 160v. 100kw.
Battery	90 cell 218AH Ni-cad.	90 cell 400AH Ni-cad.
Compressors — No. and Type	1	2
Compressors — Driven by	150v. motor	Motors
Compressors — Capacity cu. ft./min.	—	53
Exhausters — No. and Type	—	—
Exhausters — Driven by	—	—
Exhausters — Capacity cu. ft./min.	—	—
Train Heating	None	None

* SOCIÉTÉ NATIONAL DES CHEMINS DE FER (STATE).

France S.N.C.F.* 4′ 8½″ 262AD1 S.G.C.M.–M.A.N. Cie F.L. Jeumont	French Equit. Africa Congo-Ocean 3′ 6″ CC1 etc. S.G.C.M.–M.A.N. Mar.-Homécourt Jeumont	Great Britain Great Western 4′ 8½″ 1 E.E.Co. E.E.Co.,—H.L. E.E.Co.	Great Britain L.M.S. 4′ 8½″ 7069 7070 etc. E.E.Co. E.E.Co.,—H.L. E.E.Co.
Express $2–C_0–2 + 2–C_0–2$ 1938 1	Mixed traffic $C_0 + C_0$ 1936 3	Shunting C 1937 1	Shunting C 1934 1936 1 10
221·5 106·5 107′ 3″ 93′ 10″ 14′ 5½″ 63″ 39½″	82·7 82·7 50′ 4¼″ 36′ 4½″ 14′ 5″ 43¼″ —	51·5 51·5 29′ 0½″ 11′ 6″ 11′ 6″ 48½″ —	47 48·5 47 48·5 28′ 0½″ 28′ 6½″ 11′ 6″ 11′ 6″ 11′ 6″ 11′ 6″ 48½″ 48½″ — —
Four 6-cylinder four-stroke 11·8 × 15·0 Rateau turbo-ch. 950/1050 4 gens { 640v. 670kw each { 640v. 768kw	One 6-cylinder four-stroke 11·8 × 15·0 Rateau press-ch. 830/950 700v. 532kw. 700v. 600kw.	One 6-cylinder four-stroke 10 × 12 None 350 460v. 500A 230kw —	One 6-cylinder four-stroke 10 × 12 None 350 460v. 500A. 230kw —
6 twin-armature Self 640 3650 h.p. 4120 h.p.	6 single-armature Self 700 642 h.p. 720 h.p.	2 single-armature Self 500 286 h.p. 346 h.p.	2 single-armature Self 500 286 h.p. 286 h.p. 346 h.p. 360 h.p.
4200 · 53·5 22,000 51 27,550 58,400 81	950 (Full field) (Weak field) 18·6 28·6 12,770 8,290 18·0 25·5 14,800 10,470 33,000 43·5	350 12·8 8,000 8·0 12,000 30,000 60	350 12·8 8,000 8·0 12,000 30,000 60
Sim.-Cuenod-Séch. Regu. & bridge sys. — } for ea. of the 3 } four genrs. None 20 500, 630, 700	Jeumont axle- driven exciter — 6 1 step sh. auto-trans 8 500, 630, 700	Torque control 2 — — 2 None 6 375, 450, 580, 680	Torque control 2 — — 2 None 7 350, 410, 480, 620, 680
Mey.-Séch. quill 4·32 Motors only Air on loco and on rolling stock	Nose-suspension 4·78 Motors only Air on locos— Vacuum on stock	Nose sus. + coup. rods 3·938 None Air on locomotive	Nose sus. + coup. rods 3·938 None Air on locos ‡
2. 160 h.p. 6-cyl. 120/150v. 2. 150v. 90kw. 2x 90 cell 218AH Ni-cad.	None 130/170v. 50v. 180A ax-dr. 92 cell 207AH Ni-cad	None 85–100v. 100v. 11kw. 40 c. 226AH lead-acid	None 85–100v. 100v. 11kw. 40 c. 225AH. lead-acid
2 150v. motors 53 — — —	1 Motor 14·7 One 2-speed Motor —	One 2-cylinder 85v. motor 25 — — —	1 One 2-cyl 80-100v. 85v. mot. 25 25 1 — † — — —
None	None	None	None

† 85v. 3·5 h.p. motor. ‡ Vacuum on stock 1934 model.

H.E.L.

Country	GREAT BRITAIN	GREAT BRITAIN
Railway	L.M.S.	L.M.S.
Gauge	4′ 8½″	4′ 8½″
Railway Type or Number	7058	7059 etc.
Makers of Diesel Engine	Armstrong-Sulzer	Armstrong-Sulzer
Makers of Mechanical Parts	Armstrong-Whit.	Armstrong-Whit.
Makers of Electrical Parts	C.P.-Allen West	C.P.-Allen West
Type of Service	Shunting	Shunting
Axle Classification	C	C
Year First in Service	1934	1936
Total Number in Service	1	10
Total Weight in Tons	40	52·2
Adhesive Weight in Tons	40	52·2
Overall Length	28′ 0″	31′ 4½″
Total Wheelbase	13′ 0″	14′ 6″
Rigid Wheelbase	13′ 0″	14′ 6″
Driving Wheel Diameter	42″	51″
Carrying Wheel Diameter	—	—
No. of Engines, Type and Description	One 6-cylinder four-stroke	One 6-cylinder four-stroke
Cylinders Bore × Stroke (ins.)	8·7 × 11·0	8·65 × 11·0
Supercharger	None	None
B.H.P. per Engine	250	350/400
Generator Rating — Continuous	—	530v. 234kw.
Generator Rating — One Hour	—	485v. 267kw.
Traction Motors (No. and Type)	1 single-armature	1 single-armature
Motor Ventilation	motor-blower set	motor-blower set
Armature Voltage	—	600
Total Motor Rating — Continuous	—	282 h.p.
Total Motor Rating — One Hour	—	358 h.p.
Maximum Locomotive Horse Power	250	400
Locomotive Continuous Rating — Speed in m.p.h.	—	11·3
Locomotive Continuous Rating — Tractive Effort (lbs.)	—	9,100
Locomotive One-Hour Rating — Speed in m.p.h.	—	5·6
Locomotive One-Hour Rating — Tractive Effort (lbs.)	—	16,700
Maximum Tractive Effort (lbs.)	24,000	30,000
Maximum Service Speed (m.p.h.)	25	23·5
Type of Control	Servo field regu.	Servo field regu.
Motor Combinations — Series	—	—
Motor Combinations — Parallel	—	—
Motor Field Control	None	None
Running Notches	7	7
Engine Speeds (r.p.m.)	775 max.	500, 675, 875, 1000
System of Drive	Jackshaft and coupling rods	Jackshaft and coupling rods
Gear Ratio	—	11·1
Roller Bearings fitted on	None	Motors only
Mechanical Brakes	Air on locomotive	Air on locomotive
Auxiliary Engines	None	None
Auxiliary Supply	108/130v.	108/130v.
Exciter Output	—	108/130v. 8·4kw.
Battery	54 cell lead-acid	54 cell 168AH. lead-acid
Compressors — No. and Type	1	1
Compressors — Driven by	Motor	Motor
Compressors — Capacity cu. ft./min.	25	25
Exhausters — No. and Type	—	—
Exhausters — Driven by	—	—
Exhausters — Capacity cu. ft./min.	—	—
Train Heating	None	None

GREAT BRITAIN L.M.S. 4′ 8½″ 7080 etc. E.E.Co. L.M.S. Rly. E.E.Co.	GREAT BRITAIN L.M.S, Min. of Sup 4′ 8½″ 7120 etc. 70,260 etc E.E.Co. L.M.S. Rly. E.E.Co.	GREAT BRITAIN L.N.E.R. 4′ 8½″ — Armstrong-Sulzer Armstrong-Whit. L.S.E. & C. P.-A. West	GREAT BRITAIN L.N.E.R. 4′ 8½″ 8000 etc. E.E.Co. L.N.E. Rly. E.E.Co.
Shunting C 1939 40	Shunting C 1946 1944 16† 14	Mixed traffic $1-C_0-1$ 1933 1	Shunting C 1944 4†
55·3 55·3 32′ 5½″ 15′ 3″ 15′ 3″ 51″ —	47 47 29′ 1½″ 11′ 6″ 11′ 6″ 48½″ —	74 51 39′ 10″ 30′ 0″ 14′ 3″ 48″ 36″	51 51 30′ 5″ 11′ 9″ 11′ 9″ 48″ —
One 6-cylinder four-stroke 10 × 12 None 350 234kw. 250kw.	One 6-cylinder four-stroke 10 × 12 None 350 430v. 441A. 190kw. —	One 8-cylinder four-stroke 11 × 15 None 800 — —	One 6-cylinder four-stroke 10 × 12 None 350 265/530v. 243kw. —
1 single-armature Belt-driven blower 500 — 318 h.p.	2 single-armature Belt-dr. blr. 3000 c.f.m. 400 230 h.p. 270 h.p.	3 single-armature Self 800 — —	2 single-armature Belt-dr. blr. 3000 c.f.m. 400 230 h.p. 270 h.p.
350 6·9 11,500 5·6 16,300 32,500 20	350 7·3 11,000 6·5 13,200 33,000 20	880 31 7,850 16 15,000 28,500 70	350 6·1 14,000 5·5 16,200 32,000 20
Torque control — — None 10 350, 460, 580, 680	Twin-field genr. — 2 None — 340 to 680	Servo-field regu. — 3 None — Three-max. 700	Twin-field genr. — 2 None — 355 to 680
Jackshaft and coupling rods 11·2 Motors only Air on locos*	Nose-suspension + coupling rods 21·7 Motors only Air on locomotives	Nose-suspension 3·58 Motors only Vac-loco and stock	Nose-suspension + coupling rods 21·7 Motors only Air on locomotives
None 95–100v. 100v. 11kw. 40 cell 224AH. lead-acid	None 85v. 94v. 4kw belt-driven 40 c. 108AH. 64 c. 108AH. lead acid Ni-Cad	75 h.p. engine 50v. — 24 cell 158AH. lead-acid	None 85v. 85v. 4kw. 40 cell 108AH. lead-acid
1 Belts from main engine 25 1 (when fitted) 100v. motor —	1 Belts from engine 25 — — —	1 50v. motor — 1 50v. motor —	1 Belts from engine 25 — — —
None	None	None	None

* Vacuum stock on some locos. † Others on order.

Country	GREAT BRITAIN	INDIA
Railway	SOUTHERN	NORTH-WESTERN
Gauge	4′ 8½″	5′ 6″
Railway Type or Number	1 etc.	331 etc.
Makers of Diesel Engine	E.E.Co.	Armstrong-Sulzer
Makers of Mechanical Parts	Southern Rly.	Armstrong-Whit.
Makers of Electrical Parts	E.E.Co.	L.S. and E., C.P.
Type of Service	Shunting	Mixed
Axle Classification	C	$2-C_0-A1$
Year First in Service	1938	1935
Total Number in Service	3	2
Total Weight in Tons	55·2	112
Adhesive Weight in Tons	55·2	68
Overall Length	30′ 3″	56′ 8″
Total Wheelbase	11′ 6″	44′ 4″
Rigid Wheelbase	11′ 6″	—
Driving Wheel Diameter	54″	48″
Carrying Wheel Diameter	—	36″
No. of Engines, Type and Description	One 6-cylinder four-stroke	One 8-cylinder four-stroke
Cylinders Bore × Stroke (ins.)	10 × 12	13·4 × 16·9
Supercharger	None	None
B.H.P. per Engine	350	1260
Generator Rating: Continuous	162kw.	—
Generator Rating: One Hour	—	—
Traction Motors (No. and Type)	2 single-armature	4 single-armature
Motor Ventilation	Self	Forced
Armature Voltage	500	600
Total Motor Rating: Continuous	—	—
Total Motor Rating: One Hour	—	—
Maximum Locomotive Horse Power	350	1200
Locomotive Continuous Rating: Speed in m.p.h.	14·5	31
Locomotive Continuous Rating: Tractive Effort (lbs.)	7,100	10,300
Locomotive One-Hour Rating: Speed in m.p.h.	12·4	16
Locomotive One-Hour Rating: Tractive Effort (lbs.)	8,300	19,500
Maximum Tractive Effort (lbs.)	30,000	39,400
Maximum Service Speed (m.p.h.)	60	70
Type of Control	Torque control	Servo field regu.
Motor Combinations: Series	2 —	2
Motor Combinations: Parallel	— 2	2
Motor Field Control	None	—
Running Notches	6	—
Engine Speeds (r.p.m.)	375, 450, 580, 680	Max. 630
System of Drive	Nose sus. + coup. rods	Nose-suspension
Gear Ratio	4·43	3·58
Roller Bearings fitted on	None	Motors only
Mechanical Brakes	Air on locomotives	Vacuum on loco and rolling stock
Auxiliary Engines	None	110 h.p. 6-cylinder
Auxiliary Supply	100v.	—
Exciter Output	100v. 11kw.	—
Battery	40 cell 225AH lead-acid	—
Compressors: No. and Type	One 2-cylinder	1
Compressors: Driven by	85v. motor	Motor
Compressors: Capacity cu. ft./min.	25	—
Exhausters: No. and Type	—	1
Exhausters: Driven by	—	Motor
Exhausters: Capacity cu. ft./min.	—	—
Train Heating	None	None

INDIA B.B. and C.I.R. 5′ 6″ DE800 Armstrong-Sulzer Armstrong-Whit. C.P.-Allen West	INDIA N.W, G.I.P, B.B. & C.I. 5′ 6″ — Caterpillar Tractor G.E. G.E.	IRELAND Belfast & Co. Dwn 5′ 3″ D1 Harland & Wolff B. & W. H. &. W. L.S. & E.	IRELAND N.C.C., L.M.S. 5′ 3″ 28 Harland & Wolff Harland & Wolff L.S. & E.
Shunting C 1937 1	Shunting $B_0 - B_0$ 1945 30 (10 each railway)	Mixed traffic A - 1 - A 1933 1	Mixed traffic 1A + A1 1937 1
48 48 32′ 6″ 14′ 6″ 14′ 6″ 43″ —	40·6 40·6 33′ 11″ 25′ 4″ 6′ 10″ 38″ —	33 24 22′ 8″ 12′ 0″ 12′ 0″ 43″ 43″	48 23 36′ 5½″ 22′ 6″ — 43″ 43″
One 6-cylinder four-stroke 8·65 × 11·0 None 315/340 400 amps 500 amps	Two 8-cylinder V-type four-stroke 5·75 × 8·0 None 162/190 180v. 108kw. each 110v. 108kw. each	One 8-cylinder two-stroke 5·91 × 8·66 Scaveng. blower 270 410v. 175kw. 313v. 170kw.	One 8-cylinder two-stroke 7·07 × 11·82 Scaveng. blower 500 472v. 340kw. 336v. 336kw.
1 single-armature Forced — 315 amps. 475 amps.	4 single-armature Self 300 290 h.p. —	2 single-armature T.E.—Emcol type 500 200 h.p. 190 h.p.	2 single-armature T.E.—Emcol type 500 456 h.p. 450 h.p.
340 11·3 7,000 6·6 14,000 24,000 23·5	380 7·2 13,000 5·8 15,500 27,000 35	270 30 2,450 20 3,500 9,450 50	500 50 3,280 44 5,150 10,000 60
Servo-field regu. — — None 7 4. Max. 875	Split-pole exciter — } per 2 } generator 1 step shunt 11 450–1000	Ward-Leonard — 2 None 10 315, 610, 850	W-L + axle dr. exc — 2 None 12 Max. 800
Jackshaft and coup. rods 9·28 Motors only Vacuum on loco and rolling stock	Nose-suspension 11·25 Motors only Air on locomotives	Nose-suspension 5·07 Motors only Vacuum on loco and rolling stock	Nose-suspension 4·68 Motors only Vacuum on loco and rolling stock
None 108/130v. 108/130v. 8·4kw. 54 cell 130AH lead-acid	None 65v. 65v. — 32 cell 150AH lead-acid	None 100/110v. 100v. 15kw. 323AH.	None 100/110v. 110v. 35kw. 49 cell 336AH lead-acid
— — — 1 Motor —	2 Belts from engine 50 — — —	1 Engine 16 1 100v. 2·5 h.p. mot. 60	— — — 1 100v. 5·2 h.p. mot. 80
None	None	Elec fr. aux. genr.	Exhaust-gas boil.

Country	JAPAN	MADAGASCAR
Railway	GOVERNMENT	STATE
Gauge	3′ 6″	3′ 3⅜″
Railway Type or Number	—	LD1 etc.
Makers of Diesel Engine	Niigata	C.C.M. Sulzer
Makers of Mechanical Parts	Kawasaki	Alsthom
Makers of Electrical Parts	Hitachi Electric	Alsthom
Type of Service	Freight	Mixed traffic
Axle Classification	A1A + A1A	$B_0 - B_0 - B_0$
Year First in Service	1936	1939
Total Number in Service	3	5
Total Weight in Tons	—	61
Adhesive Weight in Tons	—	61
Overall Length	39′ 4½″	40′ 6″
Total Wheelbase	27′ 6½″	31′ 7″
Rigid Wheelbase	—	6′ 6″
Driving Wheel Diameter	48¼″	35½″
Carrying Wheel Diameter	34″	—
No. of Engines, Type and Description	One 8-cylinder four-stroke	One 6-cylinder four stroke
Cylinders Bore × Stroke (ins.)	11·0 × 15·0	9·85 × 12·6
Supercharger	None	Buchi turbo-ch.
B.H.P. per Engine	650	635
Generator Rating: Continuous	—	355kw.
Generator Rating: One Hour	—	352kw.
Traction Motors (No. and Type)	4 single-armature	6 single-armature
Motor Ventilation	Self	Self
Armature Voltage	—	—
Total Motor Rating: Continuous	—	—
Total Motor Rating: One Hour	—	—
Maximum Locomotive Horse Power	600	625
Locomotive Continuous Rating: Speed in m.p.h.	—	9·6
Locomotive Continuous Rating: Tractive Effort(lbs.)	—	17,600
Locomotive One-Hour Rating: Speed in m.p.h.	—	—
Locomotive One-Hour Rating: Tractive Effort(lbs.)	—	—
Maximum Tractive Effort (lbs.)	—	26,500[2]
Maximum Service Speed (m.p.h.)	37·5	37·5
Type of Control	Boosting transf.	Servo-field regul.
Motor Combinations: Series	—	—
Motor Combinations: Parallel	—	—
Motor Field Control	—	None
Running Notches	—	—
Engine Speeds (r.p.m.)	Max. 700	Max. 790
System of Drive	Nose-suspension	Nose-suspension
Gear Ratio	—	3·65
Roller Bearings fitted on	None	Motors and axles
Mechanical Brakes	Air on loco and	on rolling stock
Auxiliary Engines	None	None
Auxiliary Supply	—	—
Exciter Output	45kw.	—
Battery	Fitted	Fitted
Compressors: No. and Type	—	1
Compressors: Driven by	Fitted	motor
Compressors: Capacity cu. ft./min.	—	—
Exhausters: No. and Type	—	—
Exhausters: Driven by	—	—
Exhausters: Capacity cu. ft./min.	—	—
Train Heating	None	None

MANCHURIA STH. MANCHURIAN 4' 8½" 2000 Sulzer S.I.S. Oerlikon	MANCHURIA STH. MANCHURIAN 4' 8½" 2001 M.A.N. Esslingen Brown-Boveri	MANCHURIA STH. MANCHURIAN 4' 8½" 7000 etc. Niigati Kawasaki Hitachi Electric	MEXICO NATIONAL RLYS. 4' 8½" — Cooper-Bessemer G.E. G.E.
Mixed $B_0 - B_0$ 1931 1	Mixed $B_0 - B_0$ 1931 1	Mixed A1A - A1A 1933 2	Mixed $B_0 - B_0$ 1939 2
80 80 43' 8" 30' 2" 8' 2½" 43" —	72·5 72·5 36' 9" 25' 10" 7' 10" 44" —	116·5 78·3 49' 10½" 33' 1½" 9' 10" 44⅛" 33"	58·0 58·0 37' 0" 27' 2" 6' 8" 38" —
One 8-cylinder four-stroke 12·2 × 14·5 None 750 — 750v. 500kw.	One 7-cylinder four-stroke 11·0 × 15·0 None 700 — 750v. 435kw.	One 8-cylinder four-stroke 12·2 × 15·0 None 750 — 450kw.	One 6-cylinder four-stroke 10·5 × 13·5 None 600 380kw. —
4 single-armature Self 750 540 h.p. —	4 single-armature 2 motor-blow. sets 700 — 536 h.p.	4 single-armature — — — 900 h.p.	4 single-armature Belt-dr. blower 300 — 432 h.p.
750 — — 12·5 16,500 35,650 37·5	700 15·5 12,345 10·5 15,340 37,480 37·5	750 — — — — 35,750 37·5	600 8·0 17,900 — — 39,000 35
Diffl. cpd. genr. — 4 None — 440, 530, 620	Ward-Leonard — 4 None — 330, 500, 700	Lemp — 4 None — Max. 700	Split-pole excit. 2 2 Shunts — Max. 750
Nose-suspension 5·16 None Air	Nose-suspension 5·06 — on locomotives	Nose-suspension 4·39 None and on rolling	Nose-suspension 5·06 Motors only stock
None 150v. 150v. 50kw. 96 cell 400 AH. Ni-Cad	None 150v. 150v. 68kw. Fitted	None 110/125v. — 112v. 458AH.	None 110/125v. — 56 cell lead-acid
1 150v. motor — — — —	2 150v. motor — — — —	2 Motor — — — —	1 Double motor (125v. or 650v.) 60 — — —
None	None	None	None

Country	NORTH AFRICA	NORTH AFRICA
Railway	Various—Brit. Army	P.L.M. Afric Lines
Gauge	4′ 8½″	4′ 8½″
Railway Type or Number	65–DE–14	232ADE–1
Makers of Diesel Engine	Buda	M.A.N.
Makers of Mechanical Parts	Whitcomb	Alsthom
Makers of Electrical Parts	Westinghouse	Alsthom
Type of Service	Mixed traffic	Passenger
Axle Classification	$B_0 - B_0$	$2 - C_0 - 2$
Year First in Service	1941	1933
Total Number in Service	—	1
Total Weight in Tons	76·5	98·0
Adhesive Weight in Tons	76·5	55·0
Overall Length	40′ 0″	49′ 7¾″
Total Wheelbase	31′ 0″	39′ 4¼″
Rigid Wheelbase	7′ 0″	13′ 1⅜″
Driving Wheel Diameter	38″	49¼″
Carrying Wheel Diameter	—	39⅜″
No. of Engines, Type and Description	Two 6-cylinder four-stroke	One 8-cylinder four-stroke
Cylinders Bore × Stroke (ins.)	6·75 × 8·75	11·8 × 15·0
Supercharger	Gear-dr. blowers	None
B.H.P. per Engine	325	920
Generator Rating — Continuous	305v. 198kw. each	—
Generator Rating — One Hour	—	—
Traction Motors (No. and Type)	4 single-armature	3 single-armature
Motor Ventilation	Forced-special filters for sand	36h.p. motor-blower set
Armature Voltage	300	—
Total Motor Rating — Continuous	580 h.p.	—
Total Motor Rating — One Hour	—	—
Maximum Locomotive Horse Power	650	875
Locomotive Continuous Rating — Speed in m.p.h.	—	24·8
Locomotive Continuous Rating — Tractive Effort (lbs.)	—	10,800
Locomotive One-Hour Rating — Speed in m.p.h.	—	16·8
Locomotive One-Hour Rating — Tractive Effort (lbs.)	—	14,100
Maximum Tractive Effort (lbs.)	34,000	37,500
Maximum Service Speed (m.p.h.)	46	72
Type of Control	Diff. exc. + sp. switch	—
Motor Combinations — Series	— } per	—
Motor Combinations — Parallel	2 } generator	3
Motor Field Control	1 step shunt	Shunts
Running Notches	—	—
Engine Speeds (r.p.m.)	1200 max.	330, 500, 700
System of Drive	Nose-suspension	Nose-suspension
Gear Ratio	4·93	—
Roller Bearings fitted on	Motor only	None
Mechanical Brakes	Air-loco Air or vacuum-stock	Air on loco and on rolling stock
Auxiliary Engines	None	None
Auxiliary Supply	34v.	135v.
Exciter Output	2 × 37v. 1·75kw.	—
Battery	Two 16 cell lead-acid	64 cell 55AH lead-acid
Compressors — No. and Type	2	2
Compressors — Driven by	Engines	135v. motor
Compressors — Capacity cu. ft./min.	30	—
Exhausters — No. and Type	2	—
Exhausters — Driven by	Engines	—
Exhausters — Capacity cu. ft./min.	47·8	—
Train Heating	None	None

NORTH AFRICA P.L.M. Afric. Lines 4′ 8½″ 4ADE–1 C.C.M. Sulzer Mar.-Homécourt Alsthom	ROUMANIA STATE 4′ 8½″ — Sulzer Henschel Brown-Boveri	SOUTH AFRICA S. A. Rlys. and Hbrs. 3′ 6″ — M.A.N. A.E.G. A.E.G.	SUDAN Government Rail. 3′ 6″ — E.E.Co. E.E.Co. H.L. E.E.Co.
Mixed traffic $B_0 - B_0$ 1934 1	Passenger $2\text{–}D_0\text{–}1 + 1\text{–}D_0\text{–}2$ 1938 1	Shunting $B_0 + B_0$ 1938 —	Mixed traffic C 1937 2
72·2 72·2 46′ 0″ 33′ 9½″ 9′ 2½″ 39½″ —	218 148 96′ 2″ 85′ 4½″ 17′ 9″ 53″ 39⅜″	66 66 46′ 8″ 30′ 4″ 8′ 6″ 42″ —	45 45 28′ 10½″ 11′ 6″ 11′ 6″ 51″ —
One 8-cylinder four stroke 12·2 × 14·5 None 750 — —	Two 12-cylinder twin-bank 4-stroke 12·2 × 15·4 Buchi turbo-ch. 2200 615v. 1250kw. each 505v. 1250kw. each	Two 6-cylinder four-stroke 7·5 × 9·5 (approx.) None * 275v. 110kw. each —	One 6-cylinder four-stroke 10″ × 12″ None 350 460v 500A 230kw —
4 single-armature Self — — —	8 single-armature 2. 215v. motor- blower sets 910 3160 h.p. 3110 h.p.	4 single-armature 2 motor-blower sets — — —	2 single-armature Self 500–530 286 h.p. 420 h.p.
700 24·0 11,660 16·1 15,200 39,300 60	4400 29·8 38,400 20·8 53,800 81,500 62	530 — — — — 35,200 25	350 — — — — 28,600 35
Auto-regulator — 4 Shunts — 450, 540, 620	Servo-field regu. — per 4 generator None 8 380, 485, 625, 700	Split-pole excit. 2 2 Tappings † — 1000	Torque control 2 — — 2 None — Min 350 Max 680
Nose-suspension — Motors only Air on loco and on rolling stock	Quill and cup 5·56 Motors and axles Air on loco and stock	Nose-suspension — Motors and axles Air on loco— Vacuum on stock	Nose-sus. & coup. rods 4·68 Motors only Vacuum— loco and stock
None 135v. — 64 cell lead-acid	None 205/175v. 215v. 70kw. each 150AH. Ni-Cad.	None 110/150v. 150v. 12kw. each 110v. 145AH.	None 85v. 80–100v. 11kw. 40 cell
1 135v. motor — — — —	2 215v. 15 h.p. motors — — — —	2 120v. motors — 1 120v. motor —	— — — 1 85v. 3·5 h.p. motor —
None	None	None	None

* 265 h.p. at 1100′ above sea—205 h.p. at 6000′ above sea.
† Centrifugally-operated field-tapping switch at 8 m.p.h.

Country	Switzerland	Switzerland
Railway	Federal	Federal
Gauge	4′ 8½″	4′ 8½″
Railway Type or Number	Am4/4 1001 etc.	Am4/6 1101
Makers of Diesel Engine	Sulzer	Brown-Boveri
Makers of Mechanical Parts	S.L.M.	S.L.M.
Makers of Electrical Parts	Brown-Boveri	Brown-Boveri
Type of Service	Mixed traffic	Mixed traffic
Axle Classification	$B_0 - B_0$	$1 - D_0 - 1$
Year First in Service	1939	1941
Total Number in Service	2	1
Total Weight in Tons	65·5	92
Adhesive Weight in Tons	65·5	64
Overall Length	48′ 10″	53′ 8″
Total Wheelbase	36′ 1″	42′ 0″
Rigid Wheelbase	8′ 10½″	—
Driving Wheel Diameter	41″	48½″
Carrying Wheel Diameter	—	37⅜″
No. of Engines, Type and Description	One 8-cylinder four-stroke	One gas-turbine comp.-genr. set
Cylinders Bore × Stroke (ins.)	11·0 × 14·2	—
Supercharger	Buchi turbo-ch.	Rotary compress.
B.H.P. per Engine	1200	2300 to generator
Generator Rating — Continuous	650v. 688kw.	665v. 1145kw.
Generator Rating — One Hour	446v. 678kw.	—
Traction Motors (No. and Type)	4 single-armature	4 single-armature
Motor Ventilation	Self	Self
Armature Voltage	650	665
Total Motor Rating — Continuous	847 h.p.	1420 h.p.
Total Motor Rating — One Hour	832 h.p.	—
Maximum Locomotive Horse Power	1200	1970
Locomotive Continuous Rating — Speed in m.p.h.	45	48
Locomotive Continuous Rating — Tractive Effort (lbs.)	6,800	10,700
Locomotive One-Hour Rating — Speed in m.p.h.	31·5	31
Locomotive One-Hour Rating — Tractive Effort (lbs.)	9,600	16,800
Maximum Tractive Effort (lbs.)	18,000	28,700
Maximum Service Speed (m.p.h.)	68	68
Type of Control	Servo-field regu.	Servo-field regu.
Motor Combinations — Series	—	—
Motor Combinations — Parallel	4	4
Motor Field Control	None	None
Running Notches	9	11
Engine Speeds (r.p.m.)	430, 560, 660, 750	*
System of Drive	Br.-Bov. flex. disc	Br.-Bov. flex. disc
Gear Ratio	5·37	4·53
Roller Bearings fitted on	Motors only	Motors only
Mechanical Brakes	Air on loco and on rolling stock	Air on loco and on rolling stock
Auxiliary Engines	None	one 100 h.p.
Auxiliary Supply	155v. and 36v.	155v. and 36v.
Exciter Output	155v. 35kw.	155v. 42kw.
Battery	36v. 100AH.	36v. 100AH.
Compressors — No. and Type	1 rotary	1 rotary
Compressors — Driven by	140v. 16·3 h.p. mot	140v. motor
Compressors — Capacity cu. ft./min.	45	80
Exhausters — No. and Type	—	—
Exhausters — Driven by	—	—
Exhausters — Capacity cu. ft./min.	—	—
Train Heating	1000v. 100kw. 16⅔ cyc. A.C. heating genr.	1000v. 200kw. 16⅔ cyc. A.C. heating genr.

* Turbine 3529, 4178, 5257 r.p.m.—Generator 558, 660, 830 r.p.m.

THAILAND ROYAL STATE 3′ 3⅜″ 501 etc. Sulzer Henschel Oerlikon	THAILAND ROYAL STATE 3′ 3⅜″ Frichs Frichs Oerlikon	THAILAND ROYAL STATE 3′ 3⅜″ Frichs Frichs Oerlikon	THAILAND ROYAL STATE 3′ 3⅜″ Sulzer Henschel Oerlikon
Passenger A1A – A1A 1931 6	Passenger 2 – D_0 – 2 1931 6	Freight 2 – D_0 + D_0 – 2 1931 1	Mixed B_0 – B_0 1946 1
60 43 44′ 6¾″ 34′ 1″ 9′ 10″ 36″ 30″	83 43·5 50′ 7″ 35′ 9″ 12′ 1½″ 41½″ 30½″	122 87·2 69′ 0″ 58′ 4″ 12′ 1½″ 41½″ 30½″	46·5 46·5 37′ 1″ 30′ 6½″ 7′ 10½″ 36″ —
One 8-cylinder four-stroke — None 450 — —	Two 6-cylinder four-stroke 11·2 × 13·0 None 450/500 274kw. each 271kw. each	Two 8-cylinder four-stroke 12·2 × 13·0 None 750/800 425kw. each 420kw. each	One 6-cylinder four-stroke 9·84 × 12·6 Buchi turbo-blow 650/785 — —
4 single-armature Self — — —	4 single-armature Self 860 676 h.p. 664 h.p.	8 single-armature Self 680 1046 h.p. 1024 h.p.	4 single-armature Forced — — —
450 — — 12·8 9,130 20,680 37·5	665 30 7,930 18 14,300 32,000 40	1018 23 16,300 13 22,050 63,900 28	735 22·5 7,280 17·5 10,300 22,400 40
Diffl. cpd. genr. — 4 None — 530, 620, 700	Diffl. cpd. genr. — 4 None 15 350, 500, 600	Diffl. cpd. genr. — per 4 generator None 15 350, 500, 600	Servo-field regu. — 4 None 10 eight - max. 850
Nose-suspension — None Vacuum on locos and stock	Nose-suspension 5·26 Motors and axles Vacuum on locos and rolling stock	Nose-suspension 6·93 Motors and axles Vacuum on loco and rolling stock	Nose-suspension — Motors only Vacuum on loco and stock
— — — Fitted	None 110/160v. 31kw. each 250AH.	None 110/160v. 55kw. each 400AH.	None 32v. 150v. 150v. 32v.
1 Motor — 1 Motor —	1 Motor — 2 4 h.p. motors 97	1 Motor — 2 4 h.p. motors 97	— — — 1 rotary 150v. motor —
None	None	None	None

Country	U.S.A.	U.S.A.
Railway	Standard	Standard
Gauge	4′ 8½″	4′ 8½″
Railway Type or Number	—	—
Makers of Diesel Engine	A.L.C.O.	A.L.C.O.
Makers of Mechanical Parts	A.L.C.O.	A.L.C.O.
Makers of Electrical Parts	G.E.	G.E.
Type of Service	Shunting	Shunting
Axle Classification	$B_0 - B_0$	$B_0 - B_0$
Year First in Service	1938	1938
Total Number in Service	—	—
Total Weight in Tons	89	102·7
Adhesive Weight in Tons	89	102·7
Overall Length	44′ 5½″	45′ 5½″
Total Wheelbase	30′ 0″	30′ 6″
Rigid Wheelbase	8′ 0″	8′ 0″
Driving Wheel Diameter	40″	40″
Carrying Wheel Diameter	—	—
No. of Engines, Type and Description	One 6-cylinder four-stroke	One 6-cylinder four-stroke
Cylinders Bore × Stroke (ins.)	12·5 × 13·0	12·5 × 13·0
Supercharger	None	Buchi turbo-ch.
B.H.P. per Engine	660	1000
Generator Rating: Continuous	430v. 430kw.	473v. 638kw.
Generator Rating: One Hour	—	—
Traction Motors (No. and Type)	4 single-armature	4 single-armature
Motor Ventilation	2 belt-dr. blowers-	each 1500 c.f.m.
Armature Voltage	385	450
Total Motor Rating: Continuous	557 h.p.	850 h.p.
Total Motor Rating: One Hour	—	—
Maximum Locomotive Horse Power	660	1000
Locomotive Continuous Rating: Speed in m.p.h.	6·3	10·0
Locomotive Continuous Rating: Tractive Effort (lbs.)	29,200	34,000
Locomotive One-Hour Rating: Speed in m.p.h.	—	—
Locomotive One-Hour Rating: Tractive Effort (lbs.)	—	—
Maximum Tractive Effort (lbs.)	59,700	69,000
Maximum Service Speed (m.p.h.)	60	60
Type of Control	Split-pole diffl. exciter	-with auto-transition
Motor Combinations: Series	4 2	4 2
Motor Combinations: Parallel	— 2	— 2
Motor Field Control	— 1 step sh.	— 1 step sh.
Running Notches	4	4
Engine Speeds (r.p.m.)	250–740	250–740
System of Drive	Nose-suspension	Nose-suspension
Gear Ratio	4·68	4·68
Roller Bearings fitted on	Motors only	Motors only
Mechanical Brakes	Air on loco and	on rolling stock
Auxiliary Engines	None	None
Auxiliary Supply	75v.	75v.
Exciter Output	75v. 4·9kw.	75v. 4·9kw.
Battery	32 cell lead acid	32 cell lead acid
Compressors: No. and Type	1	1
Compressors: Driven by	Engine	Engine
Compressors: Capacity cu. ft./min.	228	228
Exhausters: No. and Type	—	—
Exhausters: Driven by	—	—
Exhausters: Capacity cu. ft./min.	—	—
Train Heating	None	None

U.S.A. N.Y. New Haven & Hartford (& others) 4′ 8½″ (3) 0701 etc. — A.L.C.O. A.L.C.O. G.E.	U.S.A. Standard 4′ 8½″ — A.L.C.O. A.L.C.O. G.E.	U.S.A. Atchison Topeka and Santa Fé 4′ 8½″ — A.L.C.O. A.L.C.O. G.E.	U.S.A. Standard 4′ 8½″ — Baldwin Baldwin Westinghouse
Mixed traffic A1A – A1A 1942 20	Mixed traffic $B_0 - B_0$ 1942 —	Passenger 3(A1A – A1A) 1946 1	Sh. and local frght $B_0 - B_0$ 1939 —
148 99 74′ 8″ 58′ 4″ 15′ 4″ 40″ 40″	107 107 54′ 11¾″ 40′ 4″ 9′ 4″ 40″ —	407 270 195′ 4″ 176′ 8″ 15′ 6″ 40″ 40″	89 89 45′ 10″ 30′ 6″ 8′ 0″ 40″ —
Two 6-cylinder four-stroke 12·5 × 13·0 Buchi turbo-ch. 1000 400v. 680kw. —	One 6-cylinder four-stroke 12·5 × 13·0 Buchi turbo-ch. 1000 473v. 638kw. —	Three 16-cylinder V. four-stroke 9·0 × 10·5 Gen. elec. superch. 2000 1490kw. each —	One 6-cylinder four-stroke 12·75 × 15·5 None 660 1000 amps —
4 single-armature 2 belt-dr. blowers* 905 1820 h.p. —	4 single-armature 2 belt-dr. blowers† 450 850 h.p. —	12 single-armature Engine-dr. blowers — 6000 h.p. —	4 single-armature Belt-dr. blowers 525 — —
2000 25·3 25,200 — — 53,000 80	1000 12 10 29,000 34,000 — — — — 69,000 72,000 70 60	6000 — — — — 151,200 85	660 5·8 29,200 — — 60,000 60
Split-pole diffl. exciter 2 — } per — 2 } generator — 1 step shunt 10 300–740	-with auto-transition 4 2 — 2 — 1 step sh. 4 270–740	G.E. amplidyne — — — — —	Diffl. exciter +load regulator 2 2 None — 625 max.
Nose-suspension 3·37 Motors and axles Air on loco and	Nose-suspension 4·06 4·68 Motors only on rolling stock	Nose-suspension — Motors and axles Air on loco and	Nose-suspension 4·86 Motors only on rolling stock
None 75v. 75v. 11·3kw. 32 cell lead-acid	None 75v. 75v. 4·9kw. 32 cell lead-acid	None — — Lead-acid	None 120v. — 56 cell, 178AH lead-acid
2 Engine 114 — — —	1 Engine 228 — — —	— — — — — —	1 Engine 145 — — —
Oil-fired boiler	Oil-fired boiler	Oil-fired boiler	None

* Each 3400 c.f.m. † Each 1500 c.f.m.

Country	U.S.A.	U.S.A.
Railway	Standard	Standard
Gauge	4′ 8½″	4′ 8½″
Railway Type or Number	—	—
Makers of Diesel Engine	Baldwin	Baldwin
Makers of Mechanical Parts	Baldwin	Baldwin
Makers of Electrical Parts	Westinghouse	Westinghouse
Type of Service	Shunting and local freight	Passenger
Axle Classification	$B_0 - B_0$	A1A – A1A
Year First in Service	1939	1945
Total Number in Service	—	—
Total Weight in Tons	107	169
Adhesive Weight in Tons	107	113
Overall Length	48′ 10″	80′ 0″
Total Wheelbase	33′ 6″	64′ 4″
Rigid Wheelbase	8′ 0″	15′ 4″
Driving Wheel Diameter	40″	40″
Carrying Wheel Diameter	—	40″
No. of Engines, Type and Description	One 8-cylinder four-stroke	Two 8-cylinder four-stroke
Cylinders Bore × Stroke (ins.)	12·75 × 15·5	12·75 × 15·5
Supercharger	None	None
B.H.P. per Engine	1000	1000
Generator Rating: Continuous	1200 amps	1200 amps
Generator Rating: One Hour	—	—
Traction Motors (No. and Type)	4 single-armature	4 single-armature
Motor Ventilation	Belt dr. blower	2 Belt-dr. blowers
Armature Voltage	525	525
Total Motor Rating: Continuous	—	—
Total Motor Rating: One Hour	—	—
Maximum Locomotive Horse Power	1000	2000
Locomotive Continuous Rating: Speed in m.p.h.	8·25	21·5
Locomotive Continuous Rating: Tractive Effort (lbs.)	33,600	28,500
Locomotive One-Hour Rating: Speed in m.p.h.	—	—
Locomotive One-Hour Rating: Tractive Effort (lbs.)	—	—
Maximum Tractive Effort (lbs.)	72,000	76,000
Maximum Service Speed (m.p.h.)	60	90
Type of Control	Diffl. exciter with	load regulator
Motor Combinations: Series	2	2 per generator
Motor Combinations: Parallel	2	—
Motor Field Control	None	None
Running Notches	—	—
Engine Speeds (r.p.m.)	625 max.	625 max.
System of Drive	Nose-suspension	Nose-suspension
Gear Ratio	4·86	2·76
Roller Bearings fitted on	Motors only	Motors and axles
Mechanical Brakes	Air on loco and	on rolling stock
Auxiliary Engines	None	None
Auxiliary Supply	120v.	120v.
Exciter Output	—	—
Battery	56 cell 260AH lead-acid	56 cell lead-acid
Compressors: No. and Type	1	2
Compressors: Driven by	Engine	Engine
Compressors: Capacity cu. ft./min.	192	115
Exhausters: No. and Type	—	—
Exhausters: Driven by	—	—
Exhausters: Capacity cu. ft./min.	—	—
Train Heating	None	Oil-fired boiler

U.S.A.	U.S.A.	U.S.A.	U.S.A.
Seaboard Air Line	Standard	Standard	Standard
Pennsylvania			
4′ 8½″	4′ 8½″	4′ 8½″	4′ 8½″
4500 —	—	—	—
Baldwin	Caterpillar	Caterpillar	Caterpillar
Baldwin	G.E.	Davenport	Davenport
Westinghouse	G.E.	G.E.	Westinghouse
Mixed traffic	Shunting and	Shunting and	Shunting and
	local freight	branch-line traffic	branch-line traffic
$2 - D_0 + D_0 - 2$	$B_0 - B_0$	B − B	$B_0 - B_0$
1945	1938	1945	1940
Several	—	—	—
258	40	22·5	40
183	40	22·5	40
91′ 6″	33′ 5″	29′ 0″	33′ 4″
77′ 10″	25′ 7″	20′ 3″	23′ 6″
16′ 3″	6′ 10″	—	—
40″	33″	33″	33″
40″	—	—	—
Two 8-cylinder	Two 8-cylinder	One 8-cylinder	Two 8-cylinder
four-stroke	V-type four-stroke	V-type four-stroke	V-type four-stroke
12·75 × 15·5	5·75 × 8·0	5·75 × 8·0	5·75 × 8·0
Buchi turbo-ch.	None	None	None
1500	190	190	190
—	265v. 111kw. each	—	—
—	—	—	—
8 single-armature	4 single-armature	2 single-armature	4 single-armature
2 motor-blower sets	Self	Forced	Forced
—	265	—	—
—	461 h.p.	—	—
—	533 h.p.	—	—
3000	380	190	380
20·2	7·2	4·3	8·0
44,500	13,000	8,000	11,800
—	5·8	3·6	5·5
—	15,500	9,500	15,650
123,000	26,400	15,000	26,400
85	35	25	35
Split-pole diffl. exc.	Split-pole exciter	Split-pole exciter	—
2 } per	— } per	2 —	2 — } per
2 } generator	2 } generator	— 2	— 2 } generator
Two steps shunt	1 step sh. auto-trans	—	—
—	—	—	—
625 max.	1000 max.	1000 max.	1000 max.
Nose-suspension	Nose-suspension	Nose-sus. + coup. rods	Nose-suspension
2·16	11·25	5·22	5·77
Motors and axles	Motors only	Motors and axles	Motors and axles
Air on loco and	on rolling stock	Air on loco and	on rolling stock
None	None	None	None
—	76v. 1·75kw.	32v.	32v.
—	—	—	—
—	32 cell lead-acid	32 cell lead-acid	32 cell lead-acid
2	2 two-stage	1	2
Motors	Engine	Engine	Engine
—	48	31	5
—	—	—	—
—	—	—	—
—	—	—	—
Oil-fired boiler	None	None	None

Country	U.S.A.	U.S.A.
Railway	Standard	Standard
Gauge	4′ 8½″	4′ 8½″
Railway Type or Number	—	—
Makers of Diesel Engine / Makers of Mechanical Parts / Makers of Electrical Parts	Electromotive Div. (General Motors)	Electromotive Div. (General Motors)
Type of Service	Shunting and short-distance freight	Shunting and short-distance freight
Axle Classification	$B_0 - B_0$	$B_0 - B_0$
Year First in Service	1939	1939
Total Number in Service	—	—
Total Weight in Tons	89	111
Adhesive Weight in Tons	89	111
Overall Length	44′ 5″	44′ 5″
Total Wheelbase	30′ 0″	30′ 0″
Rigid Wheelbase	8′ 0″	8′ 0″
Driving Wheel Diameter	40″	40″
Carrying Wheel Diameter	—	—
No. of Engines, Type and Description	One 6-cylinder V-type two-stroke	One 12-cylinder V-type two-stroke
Cylinders Bore × Stroke (ins.)	8·5 × 10·0	8·5 × 10·0
Supercharger	Scaveng. blower	Scaveng. blower
B.H.P. per Engine	660	1080
Generator Rating: Continuous	—	700kw.
Generator Rating: One Hour	—	—
Traction Motors (No. and Type)	4 single-armature	4 single-armature
Motor Ventilation	Self	2 engine-driven blowers
Armature Voltage	300	600
Total Motor Rating: Continuous	—	—
Total Motor Rating: One Hour	—	—
Maximum Locomotive Horse Power	600	1000
Locomotive Continuous Rating: Speed in m.p.h.	8·0	10·0
Locomotive Continuous Rating: Tractive Effort (lbs.)	23,700	30,400
Locomotive One-Hour Rating: Speed in m.p.h.	—	—
Locomotive One-Hour Rating: Tractive Effort (lbs.)	—	—
Maximum Tractive Effort (lbs.)	50,000	62,500
Maximum Service Speed (m.p.h.)	45	60
Type of Control	Servo-field regu.	Servo-field regu. with auto-trans.
Motor Combinations: Series	4	4 2
Motor Combinations: Parallel	—	— 2
Motor Field Control	None	None
Running Notches	—	—
Engine Speeds (r.p.m.)	275–800	275–800
System of Drive	Nose-suspension	Nose-suspension
Gear Ratio	4·13	4·13
Roller Bearings fitted on	Motors only	Motors only
Mechanical Brakes	Air on loco and on rolling stock	Air on loco and on rolling stock
Auxiliary Engines	None	None
Auxiliary Supply	74v.	74v.
Exciter Output	78v. 10kw.	78v. 10kw.
Battery	32 cell lead-acid	32 cell lead-acid
Compressors: No. and Type	1	1
Compressors: Driven by	Engine	Engine
Compressors: Capacity cu. ft./min.	178	178
Exhausters: No. and Type	—	—
Exhausters: Driven by	—	—
Exhausters: Capacity cu. ft./min.	—	—
Train Heating	None	None

U.S.A. Standard 4′ 8½″ —	U.S.A. Standard 4′ 8½″ —	U.S.A. Standard 4′ 8½″ —	U.S.A. Standard 4′ 8½″ —
Electromotive Div (General Motors)	Electromotive Div. (General Motors)	Fairbanks Morse Fairbanks Morse G.E.	Caterpillar Whitcomb Westinghouse
Express 2(A1A – A1A)(4) 1939/40 250 units	Freight 2(B_0–B_0 + B_0–B_0)(5) 1939/40 300 (approx.)	Passenger Freight 3(A1A – A1A) 1946 — (8)	Shunting B_0 – B_0 1944 —
279 191 141′ 2″ 127′ 2″ 14′ 1″ 36″ 36″	413 413 193′ 0″ 177′ 0″ 9′ 0″ 40″ —	448 311 194′ 6″ 51′ 10″ } each 15′ 5″ } unit 40″ 40″	39·3 39·3 33′ 5″ 23′ 6″ 7′ 0″ 33″ —
Four 12-cylinder V-type two-stroke 8·5 × 10·0 Scavenging blower 1080 700kw. each —	Four 16-cylinder V-type two-stroke 8·5 × 10·0 Scavenging blower 1350 (6) — —	Three 10-cylinder two-stroke op. ptn. 8·13 × (10 + 10) Scaveng. blower 2100 — —	Two 8-cylinder four-stroke 5·75 × 8·0 None 190 200v. 120kw. each —
8 single-armature Engine or motor- 1800 c.f.m. per mot. 600 — —	16 single-armature driven blowers 1900 c.f.m. per mot. 600 — —	12 single-armature 2 motor-blow. sets per unit — — —	4 single-armature 2 engine-dr. blow. each 800 c.f.m. 200 322 h.p. —
4000 40 33·3 31,400 36,500 — — — — 105,000 117 98	5400 (6) 14·5 20·5 32,500 22,500 — — — — 220,000 65 95	6000 24·0 17·6 79,200 108,000 21·4 14·5 87,900 129,000 165,000 102 75	380 7·3 13,000 5·5 16,000 22,000 35
Servo-field regu. with auto-trans. 2 — } per — 2 } generator — 1 step sh. 8 8. (275–800)	Servo-field regu. 2 — } per 2 4 } generator 1 step shunt * 8 in each comb. * 8. (275–800)	Speed switch † + split-pole exc. 2 — 2 4 1 step shunt — 300-850	Twin-field genr. auto-transition — } per 2 } generator 1 step shunt — 1000 max.
Nose-suspension 2·08 2·5 Motors and axles Air on loco and	Nose-suspension 4·08 2·85 Motors and axles on rolling stock	Nose-suspension 2·625 3·58 Motors and axles Air on loco and	Nose-suspension 5·53 None on rolling stock
None 74v. Four 78v. 10kw. 32 cell lead-acid	None 74v. Four 78v. 10kw. 32 cell lead-acid	None 75v. 12kw. — 32 cell lead-acid	None 34v. Two 37·5v. 1·75kw Two 16 cell lead-acid
4 Engine 89 — — —	4 Engine 178 — — —	3 two-stage Engine 263 — — —	2 Engine 48 — — —
Oil-fired boiler	Oil-fire boiler if required	Oil-fired boiler	None

* Four combinations—32 notches in all. † G.E amplidyne control on 8000 h.p. loco (note 8).

Country	U.S.A.	U.S.A.
Railway	Standard	Standard
Gauge	4′ 8½″	4′ 8½″
Railway Type or Number	—	—
Makers of Diesel Engine	Cummins	Cummins
Makers of Mechanical Parts	Whitcomb	Whitcomb
Makers of Electrical Parts	Westinghouse	Westinghouse
Type of Service	Shunting	Shunting and local freight
Axle Classification	B – B	$B_0 - B_0$
Year First in Service	1944	1944
Total Number in Service	—	—
Total Weight in Tons	44·7	58·0
Adhesive Weight in Tons	44·7	58·0
Overall Length	29′ 2½″	34′ 6″
Total Wheelbase	18′ 6″	23′ 0″
Rigid Wheelbase	5′ 6″	7′ 0″
Driving Wheel Diameter	33″	36″
Carrying Wheel Diameter	—	—
No. of Engines, Type and Description	Two 6-cylinder four-stroke	Two 6-cylinder four-stroke
Cylinders Bore × Stroke (ins.)	4·88 × 6·0	4·88 × 6·0
Supercharger	None	Engine-driven
B.H.P. per Engine	150	200
Generator Rating — Continuous	300v. 90kw.	200v. 120kw.
Generator Rating — One Hour	—	—
Traction Motors (No. and Type)	2 single-armature	4 single-armature
Motor Ventilation	Self	Self Forced*
Armature Voltage	300	300
Total Motor Rating — Continuous	242 h.p.	386 h.p.
Total Motor Rating — One Hour	—	—
Maximum Locomotive Horse Power	300	400
Locomotive Continuous Rating — Speed in m.p.h.	6·5 4·9	11·0 5·0
Locomotive Continuous Rating — Tractive Effort (lbs.)	11,100 14,800	9,000 18,300
Locomotive One-Hour Rating — Speed in m.p.h.	— —	— —
Locomotive One-Hour Rating — Tractive Effort (lbs.)	— —	— —
Maximum Tractive Effort (lbs.)	25,000	32,500
Maximum Service Speed (m.p.h.)	20 15	40
Type of Control	Twin-field generator	Twin-field genr. with auto-trans.
Motor Combinations — Series	— per generator	— per generator
Motor Combinations — Parallel	1	2
Motor Field Control	None	1 step shunt
Running Notches	—	—
Engine Speeds (r.p.m.)	1800 max.	1800 max.
System of Drive	Nose-sus. + coup. rods	Nose-suspension
Gear Ratio	22·1 29·3	4·12
Roller Bearings fitted on	None	None
Mechanical Brakes	Air on loco and	on rolling stock
Auxiliary Engines	None	None
Auxiliary Supply	34v.	34v.
Exciter Output	2 × (32v. 0·75kw)	2 × (32v. 0·75kw.)
Battery	16 cell lead-acid	16 cell lead-acid
Compressors — No. and Type	2	2
Compressors — Driven by	Engine	Engine
Compressors — Capacity cu. ft./min.	30	48
Exhausters — No. and Type	—	—
Exhausters — Driven by	—	—
Exhausters — Capacity cu. ft./min.	—	—
Train Heating	None	None

* Forced at 1000 c.f.m./motor.

U.S.A. Standard 4′ 8½″ — Buda Whitcomb Westinghouse	U.S.A. Baltimore and Ohio 4′ 8½″ — Winton Electromotive G.E.	U.S.A. Rock Island ‡ 4′ 8½″ — Winton Electromotive G.E.	U.S.A. Texas–Mexican 4′ 8½″ 501 etc. Baldwin Baldwin-Whitcomb Westinghouse
Shunting and local freight $B_0 - B_0$ 1943 —	Passenger $B_0 - B_0$ 1935 1	Passenger $B_0 - B_0$ 1937 6	Mixed traffic D_0 1939 7
71·4 71·4 43′ 2″ 31′ 0″ 7′ 0″ 36″ —	116 116 65′ 9″ 48′ 6″ 9′ 0″ 36″ —	98·3 98·3 62′ 4″ 42′ 6″ 8′ 6″ 36″ —	58 58 32′ 0″ 16′ 0″ 16′ 0″ 36″ —
Two 6-cylinder four-stroke 6·75 × 8·75 Engine-driven 325 305v. 198kw. —	Two 12-cylinder V-type two-stroke 8·0 × 10·0 Scavenging blower 900 700kw. each —	One 16-cylinder V-type two-stroke 8·0 × 10·0 Scavenging blower 1200 950kw. —	One 6-cylinder four-stroke 12·5 × 15·5 None 660 500v. 600kw. —
4 single-armature Self Forced† 300 580h.p. —	4 single-armature Engine-dr. blowers 600 — —	4 single-armature Engine-dr. blowers 600 — —	4 single-armature 9 h.p. mot.-blower set 500 — —
650 15·0 6·2 11,300 26,000 — — — — 40,000 40	1800 50 11,750 — — 50,400 100	1200 — — — — 55,000 117	600 — — — — 32,500 40
Twin-field genr. with auto-trans. —} per 2} generator 1 step shunt — 1200 max.	Auto load-regu. 2 —} per — 2} generator —, 1 step shunt 8 275–750	Servo-field regu. 2 — 2 4 —, 1 step shunt 8 275–750	Diffl. exciter + regulator 2 2 None — 600 max.
Nose-suspension 5·13 None Air	Nose-suspension — Motors and axles on locomotives	Nose-suspension 2·08 Motors and axles and on rolling	Nose-suspension 4·93 Motors only stock
None 34v. 2 × (37·5v. 1·75kw.) 16 cell lead-acid	One 68v. 76v. 30kw. 32 cell 450AH lead-acid	— 68–70v. 78v. 60kw. 32 cell 450AH lead-acid	None 125v. 125v. 42kw. 56 cell lead-acid
2 Engine 62 — — —	1 Aux. engine 158 — — —	1 Engine — — — —	1 Motor 80 — — —
None	Oil-fired boiler	Oil-fired boiler	None

† Forced at 4000 c.f.m./motor. ‡ Chicago, Rock Island and Pacific.

Country	U.S.A.	U.S.A.
Railway	Atchison, Topeka and Santa Fe	Bush Terminal
Gauge	4′ 8½″	4′ 8½″
Railway Type or Number	—	1–7
Makers of Diesel Engine	A.L.C.O.	Ingersoll Rand
Makers of Mechanical Parts	A.L.C.O.	G.E.
Makers of Electrical Parts	G.E.	G.E.
Type of Service	Shunting	Shunting
Axle Classification	$B_0 - B_0$	$B_0 - B_0$
Year First in Service	1933	1932
Total Number in Service	24	7
Total Weight in Tons	89·5	53·5
Adhesive Weight in Tons	89·5	53·5
Overall Length	41′ 7″	34′ 6″
Total Wheelbase	27′ 4″	22′ 6″
Rigid Wheelbase	8′ 0″	6′ 6″
Driving Wheel Diameter	40″	36″
Carrying Wheel Diameter	—	—
No. of Engines, Type and Description	One 6-cylinder four-stroke	One 6-cylinder four-stroke
Cylinders Bore × Stroke (ins.)	12·5 × 13·0	10·0 × 12·0
Supercharger	None	None
B.H.P. per Engine	600	300
Generator Rating — Continuous	—	200kw.
Generator Rating — One Hour	—	—
Traction Motors (No. and Type)	4 single-armature	4 single-armature
Motor Ventilation	Forced	Forced
Armature Voltage	—	—
Total Motor Rating — Continuous	—	—
Total Motor Rating — One Hour	—	—
Maximum Locomotive Horse Power	600	300
Locomotive Continuous Rating — Speed in m.p.h.	4·8	—
Locomotive Continuous Rating — Tractive Effort (lbs.)	28,000	—
Locomotive One-Hour Rating — Speed in m.p.h.	3·7	3·2
Locomotive One-Hour Rating — Tractive Effort (lbs.)	38,400	22,600
Maximum Tractive Effort (lbs.)	60,900	35,000
Maximum Service Speed (m.p.h.)	40	35
Type of Control	Lemp diffl. field con.	Lemp *
Motor Combinations — Series	4 2	4 2
Motor Combinations — Parallel	— 2	— 2
Motor Field Control	— 1 step shunt	— —
Running Notches	—	—
Engine Speeds (r.p.m.)	700 max.	—
System of Drive	Nose-suspension	Nose-suspension
Gear Ratio	—	4·88
Roller Bearings fitted on	Motors only	None
Mechanical Brakes	Air on loco and	on rolling stock
Auxiliary Engines	None	None
Auxiliary Supply	125v.	125v.
Exciter Output	—	125v. 25kw.
Battery	56 cell lead-acid	56cell 100AH lead-acid
Compressors — No. and Type	1	1
Compressors — Driven by	Engine	Motor
Compressors — Capacity cu. ft./min.	—	—
Exhausters — No. and Type	—	—
Exhausters — Driven by	—	—
Exhausters — Capacity cu. ft./min.	—	—
Train Heating	None	None

* With Diffl. field control Auto-transition.

U.S.A. Chicago, Milwaukee St. Paul and Pacific 4′ 8½″ 1802 Fairbanks Morse Fairbanks Morse Westinghouse	U.S.A. Erie 4′ 8½″ 25 Ingersoll-Rand Ingers. Rand, G.E. G.E.	U.S.A. Ford 4′ 8½″ — Cooper-Bessemer G.E. G.E.	U.S.A. Illinois Central 4′ 8½″ 9200 Ingersoll-Rand Ingers. Rand, G.E. G.E.
Shunting $B_0 - B_0$ 1945 6	Shunting $B_0 - B_0$ 1933 1	Local freight $B_0 - B_0$ 1938 2	Shunt. & local freight $C_0 - C_0$ 1935 1 (?)
109 109 48′ 10″ 33′ 6″ 8′ 0″ 40″ —	102·5 102·5 46′ 4″ 33′ 6″ 8′ 0″ 40″ —	118 118 52′ 0″ 40′ 4″ 8′ 0″ 40″ —	152 152 60′ 0″ 48′ 0″ — 39″ —
One 6-cylinder two-stroke op-pist. 8·12 × (10 + 10) Scavenging blower 1200 — —	One 6-cylinder four-stroke 14·73 × 16·0 None 800 525kw. —	Two 6-cylinder four-stroke 10·5 × 13·5 None 500 380kw. each —	Two 6-cylinder four-stroke 14·75 × 16·0 None 900 1650 amps —
4 single-armature 1 Engine-dr. blower 1 Motor-dr. blower — — —	4 single-armature 2 motor-blower sets 4400 c.f.m. — — —	4 single-armature Engine-dr. blower total 4400 c.f.m. 300 880 h.p. —	6 single-armature 2 motor-blower sets each 4500 c.f.m. — 580 amps each —
1000 8·3 34,600 — — 61,130 60	800 8·3 26,000 5·5 38,400 68,000 40	1000 10·0 29,000 — — 75,000 40	1800 13·8 38,800 12·0 44,400 102,000 60
Diffl. exciter 2 2 1 step shunt — 350–800	Lemp Diffl. field 4 2 — 2 —, 1 step shunt — 500 max.	Speed switch 2 2 — — 675 max.	Lemp diffl. † 3 2 } genrs. in 2 3 } series — 1 step shunt — 550 max.
Nose-suspension 4·86 Motors only Air	Nose-suspension 4·25 None on locomotives	Nose-suspension 4·53 Motors only and on rolling	Nose-suspension 4·13 Motors only stock
None 120v. — 56 cell lead-acid	None 125v. 125v. 55kw. 56 cell lead-acid	None 115v. — 48cell 171AH lead-acid	None 125v. — 56 cell lead-acid
1 Engine 246 — — —	1 Motor — — — —	2 115v. motor 55 — — —	2 Motor 200 — — —
None	None	None	None

† With Auto-transition.

Country	U.S.A.	U.S.A.
Railway	Lehigh Valley	Lehigh Valley
Gauge	4′ 8½″	4′ 8½″
Railway Type or Number	—	—
Makers of Diesel Engine	A.L.C.O.	Winton
Makers of Mechanical Parts	A.L.C.O.	Electromotive
Makers of Electrical Parts	G.E.	Electromotive
Type of Service	Shunting	Shunting
Axle Classification	$B_0 - B_0$	$B_0 - B_0$
Year First in Service	1931	1938
Total Number in Service	4	8
Total Weight in Tons	60	113
Adhesive Weight in Tons	60	113
Overall Length	37′ 4″	43′ 7½″
Total Wheelbase	24′ 0″	30′ 0″
Rigid Wheelbase	7′ 6″	8′ 0″
Driving Wheel Diameter	38″	40″
Carrying Wheel Diameter	—	—
No. of Engines, Type and Description	One 6-cylinder four-stroke	One 12-cylinder V-type two-stroke
Cylinders Bore × Stroke (ins.)	9·5 × 10·5	8·0 × 10·0
Supercharger	None	Scavenging blower
B.H.P. per Engine	300	900
Generator Rating: Continuous	—	535kw.
Generator Rating: One Hour	—	—
Traction Motors (No. and Type)	4 single-armature	4 single-armature
Motor Ventilation	Forced	Forced
Armature Voltage	—	300/600
Total Motor Rating: Continuous	—	1150 h.p.
Total Motor Rating: One Hour	—	—
Maximum Locomotive Horse Power	300	900
Locomotive Continuous Rating: Speed in m.p.h.	3·7	—
Locomotive Continuous Rating: Tractive Effort (lbs.)	19,040	—
Locomotive One-Hour Rating: Speed in m.p.h.	2·8	—
Locomotive One-Hour Rating: Tractive Effort (lbs.)	25,720	—
Maximum Tractive Effort (lbs.)	39,300	64,000
Maximum Service Speed (m.p.h.)	40	40
Type of Control	Lemp diffl. field	Servo-field regu.
Motor Combinations: Series	4 2	4 2
Motor Combinations: Parallel	— 2	— 2
Motor Field Control	—, 1 step shunt	None
Running Notches	—	—
Engine Speeds (r.p.m.)	700 max.	275–750
System of Drive	Nose-suspension	Nose-suspension
Gear Ratio	—	4·25
Roller Bearings fitted on	None	Motors only
Mechanical Brakes	Air on loco and	on rolling stock
Auxiliary Engines	None	None
Auxiliary Supply	125v.	70v.
Exciter Output	—	70v. 30kw.
Battery	56 cell lead-acid	32 cell lead-acid
Compressors: No. and Type	Fitted	1
Compressors: Driven by	—	Motor
Compressors: Capacity cu. ft./min.	—	167
Exhausters: No. and Type	—	—
Exhausters: Driven by	—	—
Exhausters: Capacity cu. ft./min.	—	—
Train Heating	None	None

U.S.A. — 4′ 8½″ — Baldwin Baldwin Allis-Chalmers	U.S.A. — 4′ 8½″ — Caterpillar Davenport G.E.	U.S.A. Union Pacific 4′ 8½″ — Boilers, B.W. Turbines & Elect. Equipt.—G.E.	U.S.A. Pittsburgh & W. Virg. 4′ 8½″ — Fairbanks Morse Fairbanks Morse —
Shunting $B_0 - B_0$ 1938 1	Shunting $B_0 - B_0$ 1938 1	Passenger $2 - C_0 + C_0 - 2$ 1939 2	Freight $B_0 - B_0$ 2. 1946–7
95 95 39′ 6″ 32′ 0″ 8′ 0″ 40″ —	94 94 42′ 0″ 32′ 0″ 8′ 0″ 40″ —	265 170 90′ 0″ 82′ 0″ — 44″ 36″	112 112 51′ 0″ 36′ 6″ 9′ 6″ 42″ —
One 6-cylinder four-stroke 12·5 × 15·5 None 660 — —	Four 8-cylinder V-type four-stroke 5·75 × 8·0 None 160/190 — —	One high-pres. and one low-pres. turbine driving common genr Boiler delivers 45,000 lbs. of steam p. hour at 1,500 lbs./sq. in. — —	One 10-cylinder two-st. opp. piston 8·12 × (10 + 10) Scavenging blower 2100 — —
4 single-armature Forced — — —	4 single-armature Aux. eng-dr. blower — — —	6 single-armature Forced 700 3600 h.p. —	4 single-armature 2 motor-blow. sets — — —
600 5·7 29,900 3·4 42,300 63,600 45	700/760 — — — — 63,000 40	Nominal 2500 24·0 30,600 — — 81,000 110	2000 14·3 42,800 — — 75,000 65
Servo-field regu. — 4 None — 600 max.	Diffl. exciter 2 } per 2 genrs. — } in series None — 1000 max.	Genr. field cont. 6 3 2 — 2 3 None — Tur. 12500/Gen. 1200	Split-pole exciter 2 2 1 step shunt — 300–850
Nose-suspension — Motors and axles Air	Nose-suspension 4·25 Motors only on locomotives	Nose-suspension 2·1 Motors and axles and on rolling	Nose-suspension 4·27 Motors only stock
None — — —	One 6-cylinder 64v. 64v. 5kw. 32 cell 215AH lead-acid	None 220v. 3 ph. 60 c. A.C. from 225 kw. gen. — Fitted	None 70v. — 32 cell lead-acid
1 Motor — — — —	1 Aux. engine 80 — — —	2 220v. 3 ph. motor — — — —	1 two-stage engine 92/260 — — —
None	None	Steam from boiler	None

Country	U.S.A.	U.S.A.
Railway	—	Elg. Joliet & East.
Gauge	4′ 8½″	4′ 8½″
Railway Type or Number	—	100
Makers of Diesel Engine	Superior	Baldwin
Makers of Mechanical Parts	Ingalls	Baldwin
Makers of Electrical Parts	Westinghouse	Westinghouse
Type of Service	Mixed	Fght. and shunt.
Axle Classification	$B_0 - B_0$	$C_0 - C_0$
Year First in Service	1946	1946
Total Number in Service	1	1
Total Weight in Tons	107	163
Adhesive Weight in Tons	107	163
Overall Length	59′ 1″	70′ 7″
Total Wheelbase	42′ 6″	51′ 4″
Rigid Wheelbase	9′ 6″	13′ 0″
Driving Wheel Diameter	43″	42″
Carrying Wheel Diameter	—	—
No. of Engines, Type and Description	One 8-cylinder four-stroke	Two 8-cylinder four-stroke
Cylinders Bore × Stroke (ins.)	12½″ × 13″	12¾″ × 15½″
Supercharger	Buchi turbo-blow.	None
B.H.P. per Engine	1650	1000
Generator Rating — Continuous	750v. 1320kw.	1200 amps
Generator Rating — One Hour	—	—
Traction Motors (No. and Type)	4 single-armature	6 single-armature
Motor Ventilation	Motor-blower sets	2 motor-blower set
Armature Voltage	375v.	525
Total Motor Rating — Continuous	—	—
Total Motor Rating — One Hour	—	—
Maximum Locomotive Horse Power	1500	2000
Locomotive Continuous Rating — Speed in m.p.h.	10·5	9·5
Locomotive Continuous Rating — Tractive Effort (lbs.)	42,800	62,500
Locomotive One-Hour Rating — Speed in m.p.h.	—	—
Locomotive One-Hour Rating — Tractive Effort (lbs.)	—	—
Maximum Tractive Effort (lbs.)	72,000	91,250
Maximum Service Speed (m.p.h.)	60	60
Type of Control	Diffl. exciter	Diffl. exciter
Motor Combinations — Series	2	— } per
Motor Combinations — Parallel	2	3 } generator
Motor Field Control	2 steps shunt	1 st. sh. (auto-trs.)
Running Notches	—	—
Engine Speeds (r.p.m.)	660	625
System of Drive	Nose-suspension	Nose-suspension
Gear Ratio	4·2	4·2
Roller Bearings fitted on	Motors and axles	Motors only
Mechanical Brakes	Air on loco and on rolling stock	Air on loco and on rolling stock
Auxiliary Engines	None	None
Auxiliary Supply	120v.	120v.
Exciter Output	—	—
Battery	56 cell lead-acid	56 cell lead-acid
Compressors — No. and Type	1	2
Compressors — Driven by	Engine	Engine
Compressors — Capacity cu. ft./min.	—	—
Exhausters — No. and Type	—	—
Exhausters — Driven by	—	—
Exhausters — Capacity cu. ft./min.	—	—
Train Heating	Oil-fired boiler	None

U.S.S.R.	U.S.S.R.	U.S.S.R.	U.S.S.R.
Turkestan	Turkestan	Turkestan	Turkestan
5′ 0″	5′ 0″	5′ 0″	5′ 0″
M.A.N.	M.A.N.	Sulzer	M.A.N.
Kolomna	Krupp	Krupp	Kolomna
Brown-Boveri	Brown-Boveri	Sécheron	Brown-Boveri
Mixed traffic	Freight	Freight	Freight
1 – D – 1	2 – E_0 – 1	2 – E_0 – 1	1 – D_0
1932	1932	1933	1931
1	1	1	1
96	133	147	81
70	89·5	103·2	72
44′ 2″	51′ 4½″	58′ 6″	40′ 2″
32′ 10″	38′ 9¼″	45′ 6″	26′ 1″
14′ 8″	18′ 9″	22′ 11″	16′ 9″
52″	48″	52″	48″
37½″	37½″	41½″	37½″
One 6-cylinder	One 6-cylinder	Two 8-cylinder	One 6-cylinder
four-stroke	four-stroke	four-stroke	four-stroke
11·0 × 15·0	17·2 × 16·5	11·0 × 15·0	11·0 × 15·0
None	None	None	None
600	1200	825	600
300v. 310kw.	747kw.	450v. 440kw. each	310kw.
300v. 350kw.	—	420v. 510kw. each	350kw.
1 single-armature	5 single-armature	5 twin-armature	4 single-armature
Forced	Forced	Self	Forced
300	—	800	600/630
416 h.p.	1000 h.p.	1032 h.p.	751 h.p.
469 h.p.	—	1185 h.p.	—
600	1200	1650	600/675
—	—	17·5	—
—	—	25,300	—
6·1	9·7	12·5	6·1
26,500	33,100	34,200	26,500
39,800	44,000	50,000	42,000
34·2	34·2	37·5	34·2
—	—	Manual	—
—	—	—	—
—	5	5	4
None	None	None	None
—	—	15	—
700 max.	400–450	460, 540, 640	700/750
Siderod	Nose-suspension	Quill and Séch. springs	Nose-suspension
5·15	5·74	6·8	5·74
None	None	Motors only	None
Air on loco and on rolling stock	Air on loco and on rolling stock	Air on loco and on rolling stock	Air and rheosta. on loco. Air on stock
None	None	None	None
140v.	140v.	150v.	140v.
61kw.	61kw.	150v. 80kw.	61kw.
160AH.	160AH.	92 cell 400AH Ni-Cad.	160AH.
1	Air supply taken from main-engine compressor	1	1
Motor		Engine	Motor
42·3		—	42·3
—	—	—	—
—	—	—	—
—	—	—	—
Exhaust-gas or	oil-fired boiler	Steam boiler	Boiler *

* Exhaust-gas or oil-fired.

Country	U.S.S.R.	U.S.S.R.
Railway	Turkestan	Turkestan
Gauge	5′ 0″	5′ 0″
Railway Type or Number		BM20, 01 etc.
Makers of Diesel Engine	M.A.N.	M.A.N., Kolomna
Makers of Mechanical Parts	Kolomna	Kolomna
Makers of Electrical Parts	Brown-Boveri	Mosc. Dyn. Wks.
Type of Service	Freight	Freight
Axle Classification	$1-D_0-1$	$2-D_0-1$
Year First in Service	1931	1933
Total Number in Service	1	2
Total Weight in Tons	92	127
Adhesive Weight in Tons	79	79
Overall Length	45′ 3″	45′ 1½″
Total Wheelbase	32′ 10″	32′ 0″
Rigid Wheelbase	14′ 10″	—
Driving Wheel Diameter	52″	48″
Carrying Wheel Diameter	37½″	35½″
No. of Engines, Type and Description	One 6-cylinder four-stroke	One 6-cylinder four-stroke
Cylinders Bore × Stroke (ins.)	11·0 × 15·0	17·2 × 16·5
Supercharger	None	None
B.H.P. per Engine	600	1200
Generator Rating { Continuous	310kw.	560kw.
Generator Rating { One Hour	350kw.	—
Traction Motors (No. and Type)	4 single-armature	4 single-armature
Motor Ventilation	Forced	Forced
Armature Voltage	600/630	440
Total Motor Rating { Continuous	751 h.p.	751 h.p.
Total Motor Rating { One Hour	—	825 h.p.
Maximum Locomotive Horse Power	600/675	1200
Locomotive Continuous Rating { Speed in m.p.h.	—	13
Locomotive Continuous Rating { Tractive Effort (lbs.)	—	20,950
Locomotive One-Hour Rating { Speed in m.p.h.	6·1	—
Locomotive One-Hour Rating { Tractive Effort (lbs.)	26,500	—
Maximum Tractive Effort (lbs.)	46,000	44,100
Maximum Service Speed (m.p.h.)	34·2	34·2
Type of Control	—	Lomonosoff
Motor Combinations { Series	—	—
Motor Combinations { Parallel	4	4
Motor Field Control	None	None
Running Notches	—	—
Engine Speeds (r.p.m.)	700/750	450 max.
System of Drive	Nose-suspension	Nose-suspension
Gear Ratio	5·74	4·32
Roller Bearings fitted on	None	—
Mechanical Brakes	Air on loco and on rolling stock	Air on loco and on rolling stock
Auxiliary Engines	None	None
Auxiliary Supply	140v.	110v.
Exciter Output	61kw.	110v.
Battery	160AH.	52 cell 81AH.
Compressors { No. and Type	1	—
Compressors { Driven by	Motor	—
Compressors { Capacity cu. ft./min.	42·3	—
Exhausters { No. and Type	—	—
Exhausters { Driven by	—	—
Exhausters { Capacity cu. ft./min.	—	—
Train Heating	Exhaust-gas or	oil-fired boiler

U.S.A.	U.S.A.	U.S.A.	FRANCE
Standard	Standard	Standard	S.N.C.F. (State)
4′ 8½″	4′ 8½″	4′ 8½″	4′ 8½″
Class F3	—	—	040—DA1 etc.
	Baldwin	Cooper-Bessemer	Baldwin
Electromotive	Baldwin	A.L.C.O.	Baldwin
	Westinghouse	G.E.	Westinghouse
Freight-Mixed-Pass.	Mixed	Light railways	Shunting
2(B − B + B − B)(5)	A1A − A1A	$B_0 - B_0$	A1A − A1A
1946	1946	1947	1946
—*	—*	1	100
407	125	62	104
407	89	62	70
202′ 8″ (50′ 8″)	58· 0″	37′ 0″	58′ 1″
191′ 0″ (39′ 0″)	—	—	43′ 8″
9′ 0″	11′ 6″	6′ 10″	11′ 6″
40″	42″	36″	42⅛″
—	42″	—	42⅛″
Four 16-cylinder	One 8-cylinder	One 6-cylinder	One 6-cylinder
V-type two-stroke	four-stroke	four-stroke	four-stroke
8·0 × 10·0	12·75 × 15·0		12·75 × 15·0
Eng.-driv. blowers	Elliott-Buchi.	Buchi	None
1665	1500	660	660
—	—	—	1000 amps
—	—	—	—
16 single-armature	4 single-armature	4 single-armature	4 single-armature
3ph A.C. mot-blow.	2 motor blower sets	Belt-driv. blower	2 eng-driv blowers
600	—	500	525
—	—	—	—
—	—	—	—
6000	1500	660	660
—	—	7·5	7·0
170,000 to 84,000†	42,800	23,600	27,750
—	—	—	—
—	—	—	—
230,000	56,000	41,700	39,200
50 to 102†	62	55	60
Servo-field regulr.	Split-pole differ	ential exciter	Sp. diffl. exc.
2 1 per	2	2 1	2 1
2 4 genr.	2	2 4	2 4
1 step sh.	1 step shunt	— 1 step sh.	— 1 step sh.
8 in each comb	—	—	—
275–800	625 max.	1000 max.	625 max.
Nose-suspension	Nose-suspension	Nose-suspension	Nose-suspension
5·42 to 2·64†	4·2		4·2
Motors and axles	Motors only	Motors only	Motors only
Air on loco	and stock.	Air on loco	Air on loco
None	None	None	None
149v. 3 phase A.C.	—	64v.	—
64v. 10kw.	64v.	74v. 3kw.	—
32 cell 426AH lead	32 cell lead-acid	32 cell lead-acid	116v.
4 two-stage	1 3-cyl. two-stage	1	1
engine	engine	engine	engine
—	—	150	—
—	—	—	—
—	—	—	—
—	—	—	—
Oil-fired boilers	Oil-fired boiler	None	None

* Several in service, large numbers on orders.
† 8 gear ratios available—max. and min. given in table.

Country	GREAT BRITAIN	GREAT BRITAIN
Railway	L.M.S.	—
Gauge	4′ 8½″	4′ 8½″
Railway Type or Number	10,000 etc.	—
Makers of Diesel Engine	E.E.Co.	Petter
Makers of Mechanical Parts	L.M.S.	Brush
Makers of Electrical Parts	E.E.Co.	Brush
Type of Service	Passenger	Shunting
Axle Classification	$C_0 - C_0$	C
Year First in Service	1947	1947
Total Number in Service	2	1 prototype
Total Weight in Tons	121	52
Adhesive Weight in Tons	121	52
Overall Length	61′ 2″	29′ 1″
Total Wheelbase	51′ 2″	11′ 9″
Rigid Wheelbase	15′ 8″	11′ 9″
Driving Wheel Diameter	42″	48″
Carrying Wheel Diameter	—	—
No. of Engines, Type and Description	One 16-cylinder V-type four-stroke	One 4-cylinder two-stroke
Cylinders bore × Stroke (ins.)	10·0 × 12·0	8·5 × 13·0
Supercharger	4 Buchi turbo	Blower
B.H.P. per Engine	1600	400
Generator Rating: Continuous	—	190kw.
Generator Rating: One Hour	1100kw.	—
Traction Motors (No. and Type)	6 single-armature	2 single-armature
Motor Ventilation	2 motor-blow. sets	motor-blower set
Armature Voltage	600	600
Total Motor Rating: Continuous	—	232 h.p.
Total Motor Rating: One Hour	—	270 h.p.
Maximum Locomotive Horse Power	1600	400
Locomotive Continuous Rating: Speed in m.p.h.	—	—
Locomotive Continuous Rating: Tractive Effort (lbs.)	15,000	—
Locomotive One-Hour Rating: Speed in m.p.h.	—	—
Locomotive One-Hour Rating: Tractive Effort (lbs.)	—	—
Maximum Tractive Effort (lbs.)	41,400	32,000
Maximum Service Speed (m.p.h.)	—	20
Type of Control	Twin fold + decomp.	Manual field
Motor Combinations: Series	2	—
Motor Combinations: Parallel	3	2
Motor Field Control	—	None
Running Notches	—	—
Engine Speeds (r.p.m.)	340–750	300–600
System of Drive	Nose-suspension	Nose-suspension
Gear Ratio	—	21·84
Roller Bearings fitted on	Motors and axles	motors
Mechanical Brakes	Vac. on loco and stock	Air on loco
Auxiliary Engines	None	1 2-cyl
Auxiliary Supply	96v.	—
Exciter Output	—	110v. 8kw.
Battery	lead-acid	12 cell lead-acid
Compressors: No. and Type	1	1 *and* 1
Compressors: Driven by	motor	motor aug engine
Compressors: Capacity cu. ft./min.	—	— —
Exhausters: No. and Type	1	—
Exhausters: Driven by	motor	—
Exhausters: Capacity cu. ft./min.	—	—
Train Heating	Oil-fired boiler	None

EIRE C.I.E.* 5′ 3″ — Mirrlees C.I.E. Brush-Allen West	U.S.A. Chesapeake & Ohio 4′ 8½″ 500 etc. Baldwin- Westinghouse	BRAZIL Sorocabana etc. 3′ 3⅜″ — Cooper-Bessemer G.E. G.E.
Shunt. and freight C 1948 5	Passenger $2-C_01+2C_01-B_0$ 1947 3	Mixed traffic C_0+C_0 1948 50
52 52 29′ 2″ 11′ 9″ 11′ 9″ 48″ —	368 † (534) 226 90′ 7″† (140′ 4″) 130′ 7″ 17′ 6″ 40″ 40″ and 36″	63 63 38′ 8″ 29′ 2″ 10′ 0″ 33″ —
One 6-cylinder four-stroke 8·5 × 13·75 Buchi turbo- 535 290kw. —	1 non-condensing turbine driving generators through 6 to 1 reduction gear 6000 568v. 1000kw. (ea. of 2 genrs with 2 arms)	One 6-cylinder four-stroke 9·0 × 10·5 None 660 — —
2 single-armature motor-blower set 700 354 h.p. 410 h.p.	8 sin.-arm. 6-pole 2 turbo-blowers 3000 c.f.m./motor 568 4960 h.p. —	6 single-armature Self — — 750
535 — — — — 25,000 25	6000 40 48,000 — — 98,000 100	600 8·25 21,900 — — 35,250 50
Manual field — — — 2 None 12 300–710	Sep. exc. genr. field — per 2 armature 1 step shunt 11 Turbo 3600-6000 r.p.m.	Split-field exciter 2 3 1 step shunt — 1000 max
+ coupling rods 12·24 Motors and axles Air on loco	Nose-suspension 2·292 Motors and axles Air on loco and rolling stock	Double reduction -angle drive Motors Air-loco Vac-stock
None — 90v. 10kw. 40 cell lead-acid	Turbines 75v. 2.75v. 9kw. genrs. —	None — 64v. 32 cell lead-acid
1 motor — — — —	Fitted — — — — —	1 engine — 1 motor —
None	Steam from loco	None

* CORAS IOMPAIR EIREANN (Irish Railways).
† Without tender: figures in brackets are with tender.

NOTES

TABLE 1

1. Carrying and adjacent driving axle mounted in common truck.
2. The Tangiers-Fez railway employs seven locomotives identical except for small differences in motor characteristics.

TABLE 2

1. Carrying and adjacent driving axle mounted in common truck.
2. The single-phase motors have intermediate rotors excited with D.C. so enabling them to operate as phase-convertors.

Running conditions :

(a) Single-phase and 3-phase machines in cascade.

(b) Single-phase machines driving.

(c) Three-phase machines driving supplied by single-phase machines as phase-convertors.

3. Air-operated weight transfer device to increase adhesive weight on starting.
4. Series-parallel control used when operating on direct current.

TABLE 3

1. Carrying and adjacent driving axle mounted in common truck.

TABLE 4

1. Rating on weak field.
2. Motors part separately excited to give increased field and torque at starting.
3. Similar locomotives operated by other railroads in one and two units, and with different gear ratios and tractive efforts.
4. Typical twin-unit locomotive. Also built in single and triple-units.
5. Standard four-unit locomotive. Also supplied in one, two or three units.
6. Modified models in production with 1500 h.p. engines giving a four-unit output of 6000 h.p. with increased tractive efforts. (See page 353.)
7. One similar loco No. 9201 with 10 cyl. 2-stroke Busch-Sulzer engine developing 2000 h.p. from cylinders 13·5″ × 16·0″. Total weight 154 tons. Max. T.E. 85,500 lbs. Continuous rating 35,100 lbs. at 16·5 m.p.h.
8. One four-unit 8000 h.p. loco. in service on the Kansas City Southern for heavy freight traffic.

KEY TO MANUFACTURERS GIVEN IN TABLES

A.B. - - -	A. Borsig A.G.
A.B.M.V. - -	A.B. Motala Verkstad
A.B.N.H. - -	A.B. Nydquist and Holm
ADAMSTHAL - -	Adamsthal Engineering Works
A.E.G. - - -	Allgemeine Elektricitäts-Gesellschaft
A.L.C.O. - -	American Locomotive Company (U.S.A.)
ALLIS-CHALMERS -	Allis-Chalmers Manufacturing Co. (U.S.A.)
ALSTHOM - -	Soc. Générale de Constructions Électriques et Mécaniques Alsthom
A.N.F. BLANC-MISSERON	Ateliers du Nord de la France à Blanc-Misseron
ANSALDO - -	Ansaldo Soc. An.
A.S.E.A. - -	Allmänna Svenska Elektriska A.B.
A.W. - - -	Sir W. G. Armstrong-Whitworth Ltd.
BALDWIN - -	The Baldwin Locomotive Works (U.S.A.)
BATIGNOLLES - -	Soc. de Construction des Batignolles
B.P. - - -	Beyer Peacock & Co. (England)
BREDA - - -	Soc. Italiano Ernesto Breda An
BROWN-BOVERI -	Brown-Boveri & Co. (Switzerland)
BRUSH - - -	The Brush Electrical Engineering Co. Ltd.
BUDA - - -	The Buda Engine Company (U.S.A.)
B.W. - - -	Babcock and Wilcox
B. & W. - -	Burmeister & Wain (Denmark)
CANADIAN G.E. Co.	The Canadian General Electric Co.
CATERPILLAR - -	Caterpillar Tractor Co. (U.S.A.)
C.C.M. SULZER -	Compagnie de Construction Mécanique Procédés-Sulzer
C.E.F. - - -	Constructions Electriques de France
CHARLEROI - -	Charleroi Electrical Works (Belgium)
C.I.E. - - -	Coras Iompair Eireann (Irish State Railways)
CIE E.M. - -	Cie Électro-Mécanique
CIE F.L. - -	Cie de Fives-Lille
C.K.D. - - -	Ceskomoravska Kolben Danck
C.N.R. - - -	Canadian National Railways
CON DEVIS - -	Construcciones Devis S.A. à Valencia
COOPER-BESSEMER -	Cooper-Bessemer Corporation (U.S.A.)
C.P.-ALLEN WEST -	Crompton Parkinson-Allen West (England)
CUMMINS - -	The Cummins Engine Co. (U.S.A.)
DAVENPORT - -	The Davenport Loco Works (Davenport-Besier Corporation) U.S.A.
E.E.Co. - -	The English Electric Co. (England)
ELECTROMOTIVE -	Electromotive Division, General Motors Corp. (U.S.A.)
ELIN - - -	" Elin " A.G. für Elektrische Industrie Werke
ESSLINGEN - -	Maschinenfabrik Esslingen
FABLOK - - -	Peirwsza Fabryka Lokomotyv w Polsce S.A.
FAIRBANKS-MORSE -	Fairbanks-Morse & Co. (U.S.A.)
FIAT - - -	Fiat Soc. An.
FRICHS - - -	A.S. Frichs Locomotive Works (Denmark)
GANZ - - -	Ganz & Co.
G.E. - - -	General Electric Co. (U.S.A.)
G.E.C. - - -	General Electric Company (English).
G.L. - - -	Garbe, Lahmeyer & Co.
HAMAR - - -	A/S Hamar J. (Norway)
HARLAND & WOLFF	Harland & Wolff Engineering Co. Ltd.

Heap & Rigby	Heap & Rigby Ltd.
Henschel	Henschel & Son A.G.
Hitachi Electric	Hitachi Electric Manuf. Co. (Japan)
H.L.	R. & W. Hawthorn Leslie & Co. Ltd.
Ingalls	Ingalls Shipbuilding & Engineering Co. (U.S.A.)
Ingersoll Rand	Ingersoll Rand & Co. (U.S.A.)
Jeumont	Forges et Ateliers de Constructions Electriques de Jeumont
Kawasaki	Kawasaki Engineering Works (Japan)
K.M.	Krauss-Maffei A.G.
Kolomna	Kolomna Engineering Works (U.S.S.R.)
Krauss	Lokomotiv Fabrik Krauss and Comp.
Krupp	Freid Krupp A.G.
Lima	Lima Locomotive Works (U.S.A.)
L.M.S.	London Midland and Scottish Rly. Co.
L.N.E.	London and North Eastern Railway Co.
L.S. & E.	Laurence Scott & Electromotors Ltd.
M.A.N.	Maschienfabrik Augsburg-Nurnberg
Marelli	Marelli (Ercole) e. C. Soc. An.
Marine-Homécourt	Cie de Forges et Aciéries de la Marine et d'Homécourt
Mirrlees	Mirrlees Bickerton & Day Ltd.
Moscow Dynamo Works	The Moscow Dynamo Works (U.S.S.R.)
M.V.	Metropolitan-Vickers Electrical Co. Ltd.
National Steel	National Steel Corporation (U.S.A.)
N.E. and B.B.	A/S N.E. and B.B. (Oslo)
Niigati	Niigata Engineering Works (Japan)
Oerlikon	Ateliers de Construction Oerlikon
Penn. RR.	Pennsylvania Railroad Shops
Per Kure	A/S Per Kure, Oslo (Norway)
Petter	Petters Ltd., Loughborough
R.H.S.E.W.	Royal Hungarian State Engineering Works
R.S.	Robert Stephenson & Co. Ltd.
S.A. Officine	S.A. Officine della Stang à Padua
Schneider	Schneider et Cie
Sécheron	Soc. Anonyme des Ateliers de Sécheron
S.G.C.M.	Soc. Générale de Constructions Mécaniques
S.I.G.N.	Suisse Industrie Gesellschaft-Neuhauson
S.I.S.	Société Industrie Suisse
Skoda	Skoda Werke A.G.
S.L.M.	Swiss Locomotive and Machine Works
S.N.C.	Spanish Naval Construction Co.
Soc. Alsacienne	Soc. Alsacienne de Constructions Mécaniques
Soc. d'Etudes	Soc. d'Etudes pour l'Electrification des Chemins de Fer Français
South Aust. Rlys.	South Australian Railways
Southern	Southern Railway Co.
S.S.W.	Siemens-Schuckert Werke A.G.
Sulzer	Sulzer Brothers Ltd.
Superior	Superior Engine Company (U.S.A.)
Tech. Br.-Boveri	Tecnomasio Italiano Brown-Boveri
Thunes	A/S Thunes Mek. Verksted Oslo
Thomson	Cie Française Thomson-Houston
Titan	Titan Electrical Works, Denmark
Vulcan	Vulcan Foundry Ltd.
Westinghouse	Westinghouse Electric Manufacturing Co.
Whitcomb	Whitcomb Locomotive Company
Winton	Winton Engine Co. (General Motors Corp.)
W.L.	Wiener Locomotiv Fabrik A.G.

INDEX

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